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Essential Nutrients in the World's Healthiest Foods

Essential nutrients are nutrients that your body can't make on its own. How these nutrients are introduced into your body may have a great impact on how well they are utilized. Nutrients do not work alone but in concert (synergistically) with other nutrients. The benefit of deriving nutrients from eating fresh whole foods such as those included on the list of the World's Healthiest Foods is that they provide not only an abundance of individual nutrients but also the variety necessary for their optimal function. This section is designed to inform you about the function of the various nutrients and which of the World's Healthiest Foods are the richest source for each of them.

- amino acids
- biotin
- calcium
- choline
- chromium
- copper
- fiber
- flavonoids
- folate
- iodine
- iron
- magnesium
- manganese
- molybdenum
- omega-3 fatty acids
- pantothenic acid
- phosphorus
- potassium
- protein
- selenium
- vitamin A
- vitamin B1 - thiamin
- vitamin B12 - cobalamin
- vitamin B2 - riboflavin
- vitamin B3 - niacin
- vitamin B6 - pyridoxine
- vitamin C
- vitamin D
- vitamin E
- vitamin K
- zinc

The World's Healthiest Foods

Amino acids are best-known as the building blocks for protein, and that reputation is well-deserved. With tens of thousands of proteins in our body—and all of them constructed from amino acids—the protein-related role of amino acids is definitely critical in support of our health (and especially the health of our immune system). Yet amino acids are also direct participants in our nervous system, detox system, and digestive system. You will find information about all of these amino acid functions and benefits in this profile. Importantly, you can also find milligram amounts for 18 different amino acids in all 100 of our food profiles by clicking on the in-depth nutritional profile link toward the end of each food profile. We do not currently rank our WHFoods based on individual or combined amino acid content. However, you will find recommended food sources for different types of amino acids (including branched chain, sulfur-containing, aromatic, and others) in the Summary of Food Sources section of this article.

Basic Description

No group of nutrients is more challenging to describe than amino acids! While some people may take this group for granted and assume that it involves interesting but unnecessary details related to protein, and while others may imagine it as a very specialized area related to body building and physical performance, amino acids are actually spotlight nutrients that all of us would do well to consider when making routine food choices.

Amino acids are most commonly described as the building blocks of protein. There are tens of thousands of unique proteins in our body, and every one of these proteins is constructed from amino acids. It does not matter whether a protein is very small and contains several dozen amino acids, or very large and contains more than 10,000 amino acids, or just average-sized and composed of 200-300 amino acids. It still consists of amino acids that have been combined together in a unique way. This relationship between amino acids and proteins has been the driving force behind nutritional research on these fascinating nutrients.

However, there is a bigger picture with respect to amino acids, and this bigger picture is also important to understand. Amino acids that are used to make proteins are referred to as "proteinogenic" amino acids. Twenty core amino acids are all that it takes to make every single protein in our body. The list below shows all 20 of these core protein-building amino acids in alphabetical order.

- Alanine
- Arginine
- Asparagine
- Aspartic acid
- Cysteine
- Glutamic acid
- Glutamine
- Glycine
- Histidine
- Isoleucine
- Leucine
- Lysine
- Methionine
- Phenyalanine
- Proline
- Serine
- Threonine
- Tryptophan
- Tyrosine
- Valine

The method that scientists have used to determine the protein-building role of these 20 core amino acids involves our genetic code. Within our genes can be found direct instructions for making all 20 of these core protein-building amino acids.

In addition to these 20 core amino acids, there are three additional amino acids that can be used by our bodies to make proteins. However, the direct instructions for making these three additional amino acids are not contained within our genes. The three additional protein-building amino acids are selenocysteine, pyrrolysine, and N-formylmethionine.

What's perhaps most surprising about these 23 protein-building amino acids is the fact that they only account for about 2% of all amino acids. Researchers estimate that an additional 750-1,000 amino acids are present in living things and are routinely used for a wide variety of purposes not related to the building of proteins. Some non-protein building amino acids have been well-researched from the standpoint of metabolism, but less well investigated from the standpoint of food. They include amino acids like ornithine, citrulline, canavanine, and GABA. We expect non-protein building amino acids to become the subject of increased research attention in future studies on foods and meal planning.

If you are starting to conclude that amino acids are somewhat like a jigsaw puzzle with many pieces that can be difficult to fit together into a coherent picture, then you are arriving at the same conclusion as many nutrition researchers! When making nutritional recommendations for our everyday diet, health scientists have expressed much more confidence in estimating our total protein needs than in estimating our need for individual amino acids.

Dispensable, Indispensable, and Conditionally Indispensable Amino Acids

Part of the difficulty in determining our need for individual amino acids involves the interconversion of amino acids that is constantly taking place in our body. Thanks to the remarkable nature of our metabolism, our bodies can create some amino acids from scratch. They can take some amino acids and convert them into others. For example, our body can take phenylalanine (Phe) and convert it into tyrosine (Tyr). It can also take serine (Ser) and convert it into glycine (Gly), and also into cysteine (Cys).

The creation and transformation of amino acids by our metabolism makes it even more difficult to determine exactly what amount of each individual amino acid we need. This added difficulty takes place for two reasons. First, even though our metabolism *can* take phenylalanine and convert it into tyrosine does not mean that it *is actually going to do so*. For example, this particular amino acid conversion requires the presence of a folate-related molecule called tetrahydrobiopterin, and if this molecule is not available, the conversion cannot occur. Second, researchers know that the ability of our body to create and transform amino acids can change at different stages of life and also in the face of very slowly developing chronic health problems like very gradual loss of blood sugar control.

One method used by researchers to help simplify amino acid recommendations has been to divide up protein-building amino acids into three basic categories: dispensable, indispensable, and conditionally indispensable. (The previous terms used to describe these categories were essential, nonessential, and conditionally essential.)

Dispensable amino acids are amino acids that our bodies are able to make under virtually all circumstances. Indispensable amino acids can never be made by our body and must be consumed through diet. Conditionally indispensable amino acids are amino acids that can be made by our body under many circumstances, but under other circumstances, cannot be made in a sufficiently reliable way to meet our needs. As shown in the chart below, all of our 20 core protein-building amino acids can be divided up and placed in one of these three categories.

Indispensable, Dispensable, and Conditionally Indispensable Amino Acids

Indispensable	Dispensable	Conditionally Indispensable
Histidine	Alanine	Arginine
Isoleucine	Asparagine	Cysteine
Leucine	Aspartic acid	Glutamine
Lysine	Glutamic acid	Glycine
Methionine	Serine	Proline
Phenylalanine		Tyrosine
Threonine		
Tryptophan		
Valine		

At WHFoods, we believe that this approach to amino acids is best used as a general guideline rather than a blueprint. As you can see, only 5/20 protein-building amino acids (25%) are classified as dispensable, and the other 75% (15/20) are either mandatory to consume from food or sometimes mandatory (depending on the circumstances). Since most of us will not know enough about our day-to-day health circumstances to make decisions about conditionally indispensable amino acids, our only reliable approach will be to make sure we get plenty of all 15 amino acids in these two categories. In short, there do not turn out to be many amino acids that we can ignore when thinking about this key group of nutrients. In our Summary of Food

Sources section, we will provide you with practical steps that can help you get ample amounts of amino acids in all three categories.

Amino Acids and Protein Quality

For more than fifty years, nutrition researchers have deliberated over the idea of "protein quality" and established various guidelines for achieving it. In its simplest form, the idea of protein quality refers to the mixture of amino acids found in any protein-containing food. A desirable mixture of amino acids is regarded as making a protein "high quality," and an undesirable mixture is regarded as making it "low quality." However, determining the amino acid mixture that is most desirable has always been—and still remains—an issue of debate.

There is one group of people for which the most desirable mixture of amino acids has never been controversial, and that group is infants. Nutrition researchers have always regarded the protein content of human milk as having the most desirable amino acid mixture for this group. And it has been relatively easy for researchers to determine the special mixture of amino acids in this food as shown in the chart below.

Amino Acid Mixture in Human Milk

Amino Acid	Milligram per Gram of Protein
Tryptophan	17
Histidine	21
Methionine+Cysteine	33
Threonine	44
Isoleucine	55
Valine	55
Lysine	69
Phenylalanine+Tyrosine	94
Leucine	96

(Food and Agriculture Organization of the United Nations, 2007)

There are three important features to notice about this chart. First, it only contains nine amino acids (or amino acid combinations). When considering protein quality, no amino acids are typically considered except for those amino acids which are classified as indispensable. (Only nine amino acids fall into that category.) Second, "methionine + cysteine" and "phenylalanine + tyrosine" are listed in sets of twos. That's because our bodies can convert methionine into cysteine and phenylalanine into tyrosine.

Finally, it is important to note that all of the indispensable amino acids listed in this chart are provided by a single food: human milk. When an infant is nursing, protein quality is taken care of through the process of breastfeeding (assuming reasonably good health on the part of the mother). No other foods are required.

For adults, however, protein quality is provided through a variety of foods, and this variety makes the most desirable mixture of amino acids more difficult to determine. One common approach taken by nutrition researchers has been to select a single protein-rich food and use its amino acid mixture as a model for protein quality. The most common foods chosen in this context have been a hen's egg and cow's milk. Using an egg as their model for the most desirable amino acid mixture, researchers at multiple universities throughout Canada have recently used a new method for analyzing amino acid requirements called Indicator Amino Acid Oxidation (IAAO), and they have come up with the following proposed desirable mixture of amino acids for adults.

Proposed Amino Acid Requirements for Adults

Amino Acid	Milligram per Gram of Protein
Histidine*	--
Tryptophan	4
Methionine (without cysteine)	13

Threonine	19
Lysine	37
Isoleucine	42
Valine	47
Phenylalanine (without tyrosine)	48
Leucine	55

Values obtained from: Elango R, Ball RO, and Pencharz PB. Recent advances in determining protein and amino acid requirements in humans. Br J Nutr. 2012 Aug;108 Suppl 2:S22-30. * Histidine recommendations not determined.

Let's take this proposed mixture of amino acids one step further, and see how it applies to a meal plan with the DV level for protein of 50 grams. The chart below shows the target level for each indispensable amino acid for any meal plan which contains 50 grams of total protein.

Proposed Amino Acid Requirements in a Meal Plan Providing 50 Grams of Protein

Amino Acid	Milligram per 50 Gram of Protein
Histidine*	--
Tryptophan	200
Methionine (without cysteine)	650
Threonine	950
Lysine	1,850
Isoleucine	2,100
Valine	2,350
Phenylalanine (without tyrosine)	2,400
Leucine	2,750

Based on values obtained from: Elango R, Ball RO, and Pencharz PB. Recent advances in determining protein and amino acid requirements in humans. Br J Nutr. 2012 Aug;108 Suppl 2:S22-30. * Histidine recommendations not determined.

Remembering that there are 1,000 milligrams in 1 gram, you can see from this chart that most indispensable amino acids are needed in amounts of approximately 1-3 grams in a meal plan providing 50 grams of protein. In our Summary of Food Sources section, we will be showing you how these recommended amounts of amino acids can be obtained in any meal plan based on our WHFoods.

You will notice that the chart above makes amino acid recommendations based on grams of protein consumed in the diet. This basis for making amino acid recommendations was the same approach used by the National Academy of Sciences (NAS) in 2002 when they established their initial guidelines for amino acid intake. However, in 2005, the NAS decided to change their basis for making amino acid recommendations. Instead of making recommendations based on grams of protein intake, they decided to base their amino acid recommendations on kilograms of body weight. (In our Public Health Recommendations section below, we actually provide you with all of the 2005 NAS recommendations for amino acids based on body weight.) While there are measurable differences between amino acid recommendations based on grams of protein intake versus human body weight, we believe that the results from these two approaches are more similar than different, and so we have incorporated both approaches into this amino acids profile. Most of our practical food examples are based on total grams of protein intake. However, in our Public Health Recommendations section, we provide you with a full set of amino acid recommendations based on human body weight as well.

Before ending this Basic Description section for amino acids, we would like to add one final note about protein quality. In the late 1960's and throughout the 1970's, one very popular approach to addressing the issue of protein quality was generally referred to as "food combining" or "protein combining." In this approach, the goal was to combine protein-containing foods on a meal-by-meal basis in such a way as to provide recommended amounts of all indispensable amino acids. This approach was often described as being especially desirable for vegetarians or strict vegetarians who consumed mostly plant foods and did not regularly consume meats, poultry, or fish. For example, strict vegetarians might be advised to combine beans with rice in order to meet their indispensable amino acid needs during a meal. Since the time period in which protein combining was first proposed, research studies have cast considerable doubt on the necessity of obtaining optimal amounts of all indispensable

amino acids at any given meal, or for that matter, on any given day. Instead, intake of indispensable amino acids over a period of several days appears to be more important for maintaining body pools of these key nutrients.

Role in Health Support

As described much more fully in our nutrient profile for protein, it is impossible to find a body system that does not rely on protein for healthy functioning. Not only do all of our cells require proteins to exist, but metabolic activities throughout the body require enzymes to proceed and these enzymes are always proteins.

However, amino acids provide us with extensive health benefits in and of themselves. In other words, even when amino acids are not combined together in the form of proteins, they still play key roles in support of our health. In this Health Support section, we're going to take the same approach for describing amino acid health benefits that we will be using in our upcoming Summary of Food Sources section. We're going to describe the health benefits of indispensable amino acids by dividing this group of nutrients up into four categories: (1) Branched-chain amino acids, (2) Sulfur-containing amino acids, (3) Aromatic amino acids, and (4) Other indispensable amino acids.

Health support role of branched-chain amino acids

The branched-chain amino acids (BCAAs) include isoleucine (Iso), leucine (Leu), and valine (Val). While most of our nutrition research on BCAAs comes from animal studies in which animals were given BCAAs in supplement form, the potential health benefits from these amino acids—in addition to their role in protein-building—seem substantial. BCAAs clearly play a role in blood sugar regulation, and have been shown to improve insulin resistance in animal studies. BCAAs have also been shown to help assure development of mitochondria (energy-producing structures) in heart muscle and skeletal muscle. In addition, they appear able to help lower risk of oxygen-based damage to cells over the course of aging, and to improve physical endurance over the course of aging as well. Once again, these research findings have typically involved research on mice or rats given BCAA supplements rather than human participants consuming BCAA-rich foods. But we look forward to follow-up studies in this area that may go further in confirming these health benefits. For practical information about increasing your BCAA intake, please see our Summary of Food Sources section.

Health support role of sulfur-containing amino acids

While methionine (Met) and Cysteine (Cys) are the only amino acids listed in our indispensable/conditionally-indispensable amino acid charts, they are actually not alone in the sulfur-containing amino acid category. Joining Met and Cys in this category are the amino acids taurine (Tau), homocysteine, (Hcy) and s-adenosyl-methionine (SAM). Together, this group of sulfur-containing amino acids play a critical role in our cardiovascular health, in the ability of our body to detoxify potentially harmful substances, and in balanced availability of B-complex vitamins. From our perspective at WHFoods, the role of Met and Cys in our body's detoxification processes is especially important. When our body is attempting to transform and eliminate potentially toxic compounds, it often relies on a cellular process that has two steps, referred to as Phase 1 and Phase 2 of detoxification. During Phase 1, potentially toxic, fat-soluble compounds are activated to make them more chemically reactive. During Phase 2, our body hooks specific molecules onto these activated compounds, enabling them to be excreted from the body.

You will not find any molecules that are more important in Phase 2 detoxification than Met and Cys. These sulfur-containing amino acids support detoxification in two ways. As reflected in its name (methionine), Met is a pivotal molecule in our body's methylation system. This system makes certain that there are enough molecules called methyl groups available through the body. Methyl groups are critical in Phase 2 detoxification, because many potential toxins must be methylated before they can be eliminated from the body. Examples of substances that require Phase 2 methylation include arsenic, lead, mercury, and polycyclic aromatic hydrocarbons (PAHs) that are found in car exhaust fumes, cigarette smoke, or smoke from the burning of wood or coal.

Cys is also critical in our body's detoxification system. This sulfur-containing amino acid occupies a pivotal place in formation of glutathione (GSH). Within our body's detoxification system, a wide variety of potential toxins must be hooked up with GSH in order to be eliminated from the body. Pesticides like atrazine and grain fumigants like methyl bromides are examples of potential toxins that must be linked up with GSH. (When GSH is linked up with these potential toxins during detoxification, the process is referred to as mercapturation.) GSH consists of three amino acids: glutamic acid (Glu), glycine (Gly), and cysteine (Cys). However, among these three amino acids in GSH, Cys plays a more central role. We would also like to note that GSH is a premier antioxidant in the body's system for balancing oxygen-related chemical reactions, and heavily relies on Cys for its antioxidant capacity. Equally important, Met and Cys and Tau have all been shown to provide us with valuable antioxidant benefits in their own right.

Health support role of aromatic amino acids

Within this category of aromatic amino acids you will find tryptophan (Try), phenylanaline (Phe), tyrosine (Tyr), and histidine (His). Since Phe can be converted into Tyr under certain circumstances, Tyr is classified as "conditionally indispensable." (In keeping with this relationship between Phe and Tyr, you will find some health research focusing only on Phe, while other studies focus equally on both Phe and Tyr. His is classified as an indispensable amino acid, and scientists have studied the ability of many plants to produce His. Researchers also know that many bacteria can produce this amino acid. However, it's not clear how much of our need for His might be provided by intestinal bacteria, nor is it clear about the relationship between His, its fellow amino acids, and proteins in general. (For example, His is the only indispensable amino acid that does not appear to impair protein synthesis or negatively impact nitrogen balance when it is deficient in the diet.)

Try, Phe, and Tyr are best-known for their role in the nervous system. Specifically, certain cells in our nervous system can take Try and convert it into serotonin (and melatonin), and other cells can take Phe and Tyr and convert them into norepinephrine and epinephrine. Serotonin, melatonin, epinephrine, and norepinephrine all function as messaging molecules in the nervous system (called neurotransmitters). These messaging molecules relay nerve signals throughout the body. Serotonin and melatonin send messages related to experiences that include relaxation, sleep, and moods. Epinephrine (also known as adrenaline) and norepinephrine (also known as noradrenaline) send messages related to "fight or flight" types of experiences involving stress, fear, heightened awareness, and emergency-type action. You may also hear these neurotransmitters being referred to as hormones since they circulate around our bloodstream and have important consequences throughout the body.

Health support role of other indispensable amino acids

The amino acids are especially important to consider in this category of other indispensable amino acids: lysine (Lys) and Threonine (Thr). Lys is especially important for genetic processes that take place in the cell nucleus. Part of these genetic events require the "packaging" of DNA into a form called chromatin. Numerous chemical components are required for formation of chromatin, and some of these components cannot be correctly produced without the involvement of Lys. In the case of Thr, there appears to be a close link between healthy dietary intake of this amino acid and proper protection of our intestinal lining. Mucins are gel-like substances secreted by cells that line our intestine, and they act as a kind of barrier in protection of those cells. Thr plays a unique role in the synthesis of mucins, and when Thr is deficient in the diet, production of mucins can also become deficient.

It's also important to note, however, that overproduction of mucins can be equally or even more problematic, since this type of imbalance has been associated with increased risk of certain cancers. However, we are not aware of any research showing possible connections between excessive dietary intake of Thr and increased risk of any cancer.

Amino acids and energy production

When considered as a group, amino acids clearly play an important role in energy production throughout the body. In order to understand this role of amino acids, it is important to think about them in a different context than the context described above involving sulfur-containing amino acids, branched-chain amino acids, and aromatic amino acids. For understanding the role of amino acids in energy production, it is important to focus on the way they can be broken down by the body. This breakdown of amino acids only happens in two ways. First, amino acids can get broken down in such a way that our body ends up turning them into blood sugar (glucose). When amino acids are broken down in this way, they are referred to as "glucogenic." Second, amino acids can be broken down in such a way that our body ends up turning them into blood ketones. When amino acids are broken down in this way, they are referred to as "ketogenic." Ketones are well-studied in the context of starvation, severe carbohydrate restriction, and prolonged fasting, where they clearly play an important role in providing energy to certain body organ systems, including the heart and the brain. However, the role of ketones in everyday health (where a balanced and healthy diet is being consumed) is not well understood. Below is a chart showing the glucogenic and ketogenic amino acids. As you will see in the chart below, some amino acids can function in both ways when they are broken down in the body.

Glucogenic and Ketogenic Amino Acids

Glucogenic Amino Acids	Ketogenic Amino Acids	Conditionally Amino Acids That Can Be Both Glucogenic and Ketogenic
Alanine	Leucine	Isoleucine
Arginine	Lysine	Phenylalanine
Asparagine		Tyrosine
Aspartic acid		

Cysteine		
Glutamic acid		
Glutamine		
Histidine		
Methionine		
Proline		
Serine		
Threonine		
Valine		

Summary of Food Sources

At the very outset, it is important to remember that all protein-containing foods contain amino acids because amino acids are the building blocks used to make proteins. For this reason, you can usually count on a protein-rich food to provide you with a good number of amino acids. This rule would definitely apply to any WHFood that ranks as a good, very good, or excellent source of protein.

At the same time, however, a food can be low in total protein and still contain a valuable amount of one or more amino acids. Bell peppers, for example, don't rank as a good, very good, or excellent source of protein in our WHFoods rating system, but they would still be considered a valuable source of the amino acid cysteine. (Our in-depth nutritional profile for bell peppers show them to contain 20 milligrams of cysteine in a 28-calorie, one-cup serving.)

When considering food sources of indispensable amino acids, we believe it is helpful to break them down into the following four categories: (1) Branched-chain amino acids, (2) Sulfur-containing amino acids, (3) Aromatic amino acids, and (4) Other indispensable amino acids. The chart below shows how specific amino acids fit into these four categories (The * in the chart denotes that these amino acids aer conditionally indispensable.)

Chart for Organizing Amino Acid Food Choices

Branched-chain amino acids (BCAAs)	Sulfur-containing amino acids (SAAs)	Aromatic amino acids	Other indispensable amino acids
Isoleucine	Methionine	Histidine	Lysine
Leucine	Cysteine*	Phenylalanine	Threonine
Valine		Tyrosine*	
		Tryptophan	

With this chart in mind, let's take a look at your best food options in each of these four amino acid categories.

Best Food Options for Branched-Chain Amino Acids (BCAAs)

Branched-chain amino acids (isoleucine, leucine, and valine) tend to be most concentrated in fish, eggs and dairy, sea vegetables, and soy foods. Interestingly, our need for total BCAAs may fall into the range of 7 grams per 50 grams of protein —the highest total among our four categories. It would take about 8 ounces of tofu, cod or shrimp to provide you with this total from any one of these foods. One cup of grass-fed yogurt would provide you with about 25-33% of this amount, as would one ounce of grass-fed cheese.

Best Food Options for Sulfur-containing Amino Acids (SAAs)

As reviewed earlier, protein quality recommendations for sulfur-containing amino acids are sometimes based on combined intake of methionine+cysteine, and sometimes based on intake of methionine alone (since methionine can be converted by the body into cysteine under certain circumstances). We like the idea of getting both sulfur-containing amino acids in your meal plan. The target goal described earlier for meal plan providing 50 grams of protein established 650 milligrams of methionine as the recommended daily amount. From our perspective, it would not be a bad idea at all to obtain this 650-milligram level for methionine, and to get a substantial amount of cysteine as well. You could accomplish this goal with a single serving of many

fish. Let's take salmon as an example. A single 4-ounce serving of salmon provides you with 790 milligrams of methionine and 280 milligrams of cysteine. A one cup serving of most legumes will provide you with about half of your daily requirement for sulfur-containing amino acids. From the nuts and seeds category, you will get about 25% of your daily requirement from a single 2-ounce serving. It is worth adding an additional note here about plant foods that are rich in sulfur compounds, while not quite as rich in sulfur-containing amino acids. Sulfur-rich plant foods can still make great additions to your health, even if their sulfur is not primarily found in their amino acids. Foods belonging to this category would include allium vegetables like garlic, onions and leeks and cruciferous vegetables like broccoli and Brussels sprouts.

Best Food Options for Aromatic Amino Acids

In this aromatic amino acid category we will focus on two particular amino acids, namely, phenylalanine and tryptophan. These aromatic amino acids are especially important in helping our nervous system function properly, since they are the basis for making key messaging molecules used to send signals in our nervous system. In a meal plan providing 50 grams of protein, the target level for these two aromatic amino acids is very different, however. For phenylalanine, the recommended intake about is 2,400 milligrams. By contrast, the recommended amount for tryptophan is only 200 milligrams.

Let's take tryptophan first. You'll be getting about 50% of your daily tryptophan from one serving of nuts or seeds; about 30% from a serving of whole grains; and about 15-25% from one serving of many vegetables. If you move over into the dairy and eggs category, you will find one cup of grass-fed yogurt to be providing you with about 20% of your daily tryptophan and one egg or one ounce of cheese to contain about 40%. One cup of beans or 4 ounces of tofu will get you over the 100% level. Four ounces of salmon will provide you with 150%, and 4 ounces of chicken will contain over 200%. So as you can see, there are a wide variety of different ways for you to get plenty of this indispensable amino acid.

With a target goal of 2,400 milligrams, phenylalanine will be more challenging. Let's start with the easiest combinations first. Approximately 40-50% of this amount will be provided by four ounces of most fish and most meats. One serving of most legumes will get you one third of the way there. For example, you will get 820 milligrams in one cup of black beans, and 870 milligrams in four ounces of tofu. Roughly 15% of your daily requirement can be provided by one serving of most nuts and seeds. The going rate of phenylalanine for most vegetables is approximately 5% per serving. So let's say your meal plan for the day includes one serving of tofu, two servings of nuts and seeds, and five servings of vegetables. That combination should put you very close to the place you need to be for meeting your phenylalanine needs.

Best Food Options for Other Indispensable Amino Acids

There are two remaining amino acids that need to be accounted for in this last category: lysine and threonine. In the case of lysine, we are talking about an amino acid closely involved in genetic metabolism and cell signaling. In the case of threonine, we are also talking about a cell signaling-related amino acid that is especially important in phosphorylation reactions involving receptor serine/threonine kinases. For lysine, the recommended daily intake level is 1,850 milligrams, and for threonine, the level is 950 milligrams.

In the case of lysine, the most standout plant foods are legumes. A one-cup serving of most beans will provide you with about 50-60% of the lysine you need, and four ounces of tofu will provide you 60-65%. One serving of nuts or seeds will usually provide about 20% of your daily lysine, and many vegetables can provide you with about 10% or more of the lysine you need per serving (usually one cup). So you will be able to build a full day's supply of lysine by including this variety of foods in your meal plan. If your meal plan includes foods from the dairy and egg group, you will be getting about 25% of your daily lysine from one egg, roughly the same percentage from one ounce of cheese, and more like 35% from one cup of grass-fed yogurt. Four ounces of fish or four ounces of chicken will provide you with more than 100% of your daily lysine all by itself.

Role of Gut Bacteria in Supplying Indispensable Amino Acids

In the ongoing list of reasons why a healthy digestive tract is so important to our nourishment, researchers have now added the role of intestinal bacteria in providing us with indispensable amino acids. Studies have shown that a healthy balance of intestinal bacteria can increased the availability of both methionine and lysine to our cells. (In scientific terms, there can be "net synthesis" of these amino acids in our large intestine, where the amount of lysine and methionine produced by intestinal bacteria exceeds the amount of these amino acids that are consumed by them.) Since certain lactic acid bacteria have also been shown to synthesize the amino acid histidine, there have also been questions raised about the possible role of intestinal bacteria in increasing availability of this amino acid.

Summarizing Food Sources of Indispensable Amino Acids

There are several conclusions that can be drawn from this food-based look at indispensable amino acids. First, among the plant foods, legumes can be a particularly helpful food group. Any person avoiding animal foods and concerned about amino acid intake would do well to emphasize beans, lentils, split peas, tofu, tempeh, and other legumes in their meal plan. Second, nuts and seeds can also make substantial contributions to healthy amino acid intake. It would be wrong to overlook their role here. Third, when most people hear the very common recommendation to include at least five servings of fresh vegetables in their daily meal plan, they usually think about the value of these foods in terms of vitamins and minerals. But when vegetables are consumed in generous amounts, they can provide a surprisingly high percentage of the indispensable amino acids that we need. Finally, you will notice that we did not discuss the role of fruits as a food group when calculating amino acids needs. This group does indeed provide small amounts of indispensable amino acids, but not enough to serve as a basis for healthy amino acid intake. One cup of blueberries, for example, will provide about 1.5% of your daily phenylalanine, 1% of your daily lysine, and 3% of your daily threonine.

Because animals have muscles where plants do not, animal foods clearly serve as more concentrated sources of protein and can provide a leg up in meeting amino acids needs if enjoyed and included on a somewhat regular basis in a meal plan. However, we would like to point out that the incorporation of animal foods into a meal plan does not automatically mean that your indispensable amino acid requirements are a "slam dunk." It is still important to consider the broad spectrum of amino acid guidelines described above when formulating a meal plan, even if animal foods are included in that meal plan.

Food Source Analysis not Available for this Nutrient

Impact of Cooking, Storage and Processing

Below temperatures of 100°C (212°F), we've seen little evidence of unwanted changes in a food's amino acids, Most of the research that we have seen has been conducted on animal versus plant foods.

Beginning as low as room temperature, fascinating chemical reactions can occur in some foods that involve specific types of amino acids and specific types of sugars. These reactions are called Maillard reactions. A more common name for these interactions is "browning" or "non-enzymatic browning." It seems that 5-carbon simple sugars (like ribose) tend to react more quickly with amino acids than larger 6-carbon sugars (like glucose). And on the amino acid side of the equation, amino acids like lysine with more than one amine group tend to react more quickly. Other aspects of amino acids—like the sulfur contained in cysteine—can also result in unique flavors associated with browning. Sugar alcohols like sorbitol do undergo Maillard reactions, and that is why you often see less browning in baked goods that have been sweetened with these sugar alcohols rather than sugars like glucose, fructose, or sucrose. To summarize: Maillard reactions are associated not only with color ("browning") but also with flavor. Brown bread crusts, browned toast, browned meat, roasted coffee beans all owe their unique flavors and aromas, at least in part, to Maillard reactions. These reactions, in turn, depend on the presence of amino acids and sugars.

Maillard reactions take place on a continuum. At room temperatures and over a short period of time, you are not going to end up with much browning or change in flavor. As temperature increase and time of heating increases, you are going to see more color change and more change in flavor. We have not seen research showing unwanted health risks to be associated with Maillard reactions when amino acid-rich foods like meats are cooked at moderate temperatures for sufficient times to kill potentially problematic microorganisms and create new flavors in the meats. However, at the other end of the continuum—which might be described as the later stages of the Maillard reaction—one possible result of amino acid and sugar interactions involves formation of molecules called advanced glycation end-products, or AGEs. The cooking methods that appear mostly likely to increase AGE formation in amino acid-rich foods include grilling, searing, and frying. AGEs can be formed not only in our food, but also in our body. Relatively recent research indicates that AGEs formed in our food can get absorbed up into our body and contribute to the "pool" of AGEs that have already been formed by our own metabolism. Whether derived from food or formed inside of our body, we know that AGES can contribute to increased risk of chronic diseases including atherosclerosis, osteoarthritis, cataracts, neurodegenerative diseases, and cataracts. The risk of AGE formation during late stage Maillard reactions is one of the reasons that we avoid grilling, searing, and frying of our WHFoods. A second area of concern in the cooking of amino acid-rich foods involves possible formation of acrylamides. Potato chips, French fries, and grain-based coffee substitutes are processed foods in which acrylamide formation has been most extensively studied. You can find many more details in our Q & A What is acrylamide and how is it involved with food and health ?

As addressed earlier in this profile, food processing can cause damage and loss of amino acids in food, as well as imbalances in overall amino acid composition. A meal plan based on whole foods will provide you with balanced patterns and varieties of amino acids that are simply not possible to obtain from processed foods.

Risk of Dietary Deficiency

Our relatively high average daily intake of protein in the U.S.—close to 80 grams in the National Health and Nutrition Survey data from 2009-2010—also means that we average about 80,000 milligrams of amino acids in our daily meal plan. Since our need for any particular indispensable amino acid is typically less than 10 grams, you can see how our odds of getting enough indispensable amino acids are fairly good. We haven't seen studies showing outright deficiency of amino acids in healthy U.S. adults with average dietary intake.

As described earlier, it can be difficult to get the full variety of indispensable amino acids without a meal plan that includes regular intake of foods from a variety of food groups. Fruits would clearly be the least helpful food group for improving amino acid intake. If vegetables are used simply as a kind of "garnish" in very small amounts, they are also not particularly helpful in preventing amino acid deficiency. However, when consumed in generous amounts (for example, 1-2 cups or more per serving), they can make a very substantial contribution to our amino acid needs. At the top of the plant food list for amino acids, however, we would have to single out beans and legumes, followed by nuts and seeds. With regular daily servings of beans/legumes, nuts/seeds, and generous combined servings of fresh vegetables (4-5 cups total), your risk of individual amino acid deficiencies should stay relatively low. As you can see, we believe that no animal food intake is required to keep your risk of amino acid deficiencies relatively low, provided that you enjoy generous amounts of plant foods from these different food groups in our meal plan. You don't need to worry about combining these different groups on a meal-by-meal basis, or even within a single day. But you do need consume generous amounts from these plant food groups over a period of several days.

One additional point seems important in this discussion of plant food groups and dietary deficiency of amino acids. If you consumed 2 cups of legumes (about 500 calories), 1/2 cup of nuts and seeds (about 400 calories), and 5 cups of vegetables (about 150 calories), your calorie total would still only be about 1000-1100 calories. This very low calorie level would raise the potential for our body to divert amino acids away from some of their health benefit functions and toward increased breakdown for use in energy production. So it is important to maintain a healthy level of total calorie intake that will not only allow for sufficient intake of amino acids but also avoid the need to use them for energy production purposes. Remember that key food groups like fresh fruits and whole grains will typically plan an important role in fleshing out your overall daily meal plan.

Food processing is a final area of concern with respect to amino acids and dietary deficiency. Processed prepackaged foods can place us at risk for amino acid deficiency in two ways. First, amino acids can simply be damaged or lost during processing. For example, we think about the germ portion of grains (like wheat germ) as a concentrated source of vitamins and minerals. This idea on our part is correct! But wheat germ is also a concentrated source of amino acids, and if this portion of the grain is removed during processing, it is not only vitamins and minerals that are lost, but amino acids as well. Second, food processing can also create unwanted imbalances in amino acid intake. During food processing, proteins are sometimes extracted out of whole foods and then added back later on during the manufacturing process. These steps can change the natural amino acid balance that was present in the whole food. In this context, it is also worth remembering that many amino acids in whole foods are not found in their proteins but in smaller peptides (short amino acid chains) or in their individual form.

Other Circumstances that Might Contribute to Deficiency

In our nutritional profile for protein, we describe the close connection between protein status and immune function. Adequate total protein intake and balanced intake of indispensable amino acids both play important roles in healthy immune function. For this reason, immunodeficiency-related health problems can contribute to a greater need for indispensable amino acids and a greater risk of amino acid deficiency. In fact, there is some evidence that immune system challenges related to aging can bring with them increased risk of both protein and amino acid deficiencies.

Increased protein and amino acid needs can occur with general physical overexertion, high-demand body building, and athletic training. For this reason, increased risk of amino acid deficiency can also occur under these circumstances.

Since intestinal bacteria may play an important role in making certain amino acids available to us in adequate supply—particularly lysine, methionine, and potentially histidine—digestive tract problems involving bacterial imbalance in the large intestine may put us at greater risk of certain amino acid deficiencies.

Relationship with Other Nutrients

Most simply put, amino acids are constantly interacting with a wide variety of other nutrients in our body. Amino acids play a central role in many basic areas of metabolism. They are so intricately interwoven into metabolic process that many metabolic processes are actually named for their amino acid components. Examples include the Glucose-Alanine Cycle, the Methionine Cycle, and the s-adenosylmethionine Cycle. Especially in the case of dispensable amino acids (including alanine, asparagine,

aspartic acid, glutamic acid, and serine), the metabolism of carbohydrates, fatty acids, organic acids, and amino acids is highly overlapping and impossible to separate.

You can also find unique relationships between specific amino acids and specific nutrients. For example the metabolism of methionine, cysteine, tyrosine, phenylalanine, and tryptophan is very closely related to the B-complex vitamins B6, B12, choline, and folate.

Risk of dietary Toxicity

We have not seen any research studies showing risk of amino acid toxicity from whole food intake. In keeping with the lack of demonstrated problems in this area of amino acid toxicity from foods (versus amino acid supplements), the National Academy of Sciences (NAS) decided not to set Tolerable Upper Limits (ULs) for amino acids from food in its establishment of the amino acid Dietary Reference Intakes (DRIs).

However, we do not believe that this same lack of toxicity risk applies to dietary supplements which can sometimes contain high doses of select amino acids. In its establishment of the amino acid DRIs, the NAS reviewed evidence for potential risks related to amino acid supplementation in the case of each indispensable amino acid, and in some cases the NAS found evidence of potential adverse effects from isolated high doses. As is the case throughout our website, these differences between whole food forms of nutrients like amino acids and supplemental forms of the same nutrients are part of the reason that we encourage a focus on whole foods for intake of all nutrients—including all amino acids.

Disease Checklist

- Exhaustion from physical overexertion
- Depression
- Anxiety
- Inadequate detoxification
- Liver disease
- Immunodeficiency-related problems
- Digestive problems involving intestinal bacteria
- Emergency and trauma

Public Health Recommendations

The National Academy of Sciences (NAS) has set Dietary Reference Intake (DRI) levels for amino acid intake based on a person's age, gender, and body weight. These DRI recommendations are set for indispensable amino acids only. The chart below shows the entire set of amino acid DRIs, based on milligrams of each amino acid required for every 2.2 pounds (1 kilogram) of body weight. All of the DRI recommendations below are established in the form of Recommended Dietary Allowances (RDAs), except in the case of infants under 6 months of age, which are established as Adequate Intake (AI) levels.

Age/gender	His	Iso	Leu	Lys	Met+Cys	Phe+Tyr	Thr	Trp	Val
0-6 mos	36	88	156	107	59	135	73	28	87
6-12 mos	32	43	93	89	43	84	49	13	58
1-3 yrs	21	28	63	58	28	54	32	8	37
4-8 yrs	16	22	49	46	22	41	24	6	28
9-13 yrs, boys	17	22	49	46	22	41	24	6	28
9-13 yrs, girls	15	21	47	43	21	38	22	6	27
14-18 yrs, boys	15	21	47	43	21	38	22	6	27
14-18 yrs, girls	14	19	44	40	19	35	21	5	24
19+ years	14	19	42	38	19	33	20	5	24
Pregnancy	18	25	56	51	25	44	26	7	31
Lactation	19	30	62	52	26	51	30	9	35

Abbreviations: His — histadine, Iso — isoleucine, Leu — leucine, Lys — lysine, Met + Cys — total of methionine and cysteine, Phe + Tyr — total of phenylalanine and tyrosine, Thr — threonine, Try — Tryptophan, Val — valine. Data are presented in mg/kg of body weight per day.

As described earlier in this profile, researchers at multiple universities throughout Canada have recently used a new method for analyzing amino acid requirements called Indicator Amino Acid Oxidation (IAAO), and they have come up with the following proposed desirable mixture of amino acids for adults based not on age, gender, and body weight, but rather on grams of protein consumed. The chart below show their recommendations for intake of indispensable amino acids in milligrams for every gram of protein consumed.

Proposed Amino Acid Requirements for Adults

Amino Acid	Milligram per Gram of Protein
Histidine*	--
Tryptophan	4
Methionine (without cysteine)	13
Threonine	19
Lysine	37
Isoleucine	42
Valine	47
Phenylalanine (without tyrosine)	48
Leucine	55

Values obtained from: Elango R, Ball RO, and Pencharz PB. Recent advances in determining protein and amino acid requirements in humans. Br J Nutr. 2012 Aug;108 Suppl 2:S22-30. * Histidine recommendations not determined.

Due to a lack of evidence regarding toxicity risk from food intake of amino acids, the National Academy of Sciences (NAS) did not establish Tolerable Upper Limits (ULs) for intake of any amino acid.

There is no Daily Value (DV) for any amino acid. In addition, due to the complicated nature of dispensable, indispensable, and conditionally indispensable amino acids—as well as the flexibility that all of us have in obtaining balanced intake of amino acids over the course of several days—we chose not to establish daily requirements for amino acids in our food rating system. However, you can find out the specific amount of 18 different amino acids in every one of our 100 WHFoods (as well as our 17 Herbs & Spices) in their in-depth nutritional profiles.

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The World's Healthiest Foods

World's Healthiest Foods rich in biotin		
Food	Cals	DRI/DV
Almonds	132	49%
Sweet Potato	180	29%
Eggs	78	27%
Onions	92	27%
Oats	152	26%
Tomatoes	32	24%
Peanuts	207	21%
Carrots	50	20%
Walnuts	196	19%
Salmon	158	15%

Basic Description

Biotin is a B-complex vitamin that has been identified as a necessary nutrient for a century, but has only begun to be understood in the past two decades. It has also been previously referred to as coenzyme R, vitamin H, and vitamin B7, with the different names attesting to the confusion surrounding its role in normal metabolism.

Biotin first came to the attention of researchers for what is still its most famous characteristic—that raw egg whites can interfere with biotin nutrition. (For more on this please see the Impact of Cooking, Storage, and Processing section below.) More recently, we have learned about its central role in many pathways of metabolism. Most importantly, we see that biotin plays key roles in fat and sugar metabolism, roles that make deficiency of biotin show up in multiple and unrelated ways.

There is still much we don't know about biotin, however. Importantly, there are still major questions about how much biotin is needed to prevent deficiency.

We also have only a partial understanding of how much biotin is found in commonly eaten foods. Many of the foods that our charts say do not contain biotin actually more accurately contain an unknown quantity of the vitamin. Soybeans, mushrooms, and pumpkin and sunflower seeds are examples of foods with substantial amounts of biotin that are not quantified in the databases we use to determine the biotin concentrations in foods.

Some of the difficulty we have in determining the food content of biotin lies in the shortcomings of our methods for biotin analysis in the laboratory. Three primary methods of biotin analysis involve (1) bacterial growth studies, (2) studies in which biotin binds to a protein called avidin (or sometimes streptavidin), and (3) dye-based studies using a chemical called 4'-hydroxyazobenzene-2-carboxylic acid. All three methods have known limitations, and the results of these different methods can be quite inconsistent. In short, researchers are still figuring out how to accurately measure the biotin content of food.

While we are still learning about how rich many of the World's Healthiest Foods are as biotin sources, we already know that we have tomatoes as an excellent source of biotin, and almonds as a very good source. Among the World's Healthiest Foods, you will also find 5 additional very good sources of biotin and 13 good sources of this vitamin.

Role in Health Support

Blood sugar balance

Diets low in biotin impair the production of insulin, a key hormone in the balancing of blood sugar. More recently, researchers have shown that deficiency of biotin also affects the way insulin acts on cells, giving a second reason that low biotin intake potentially creates problems.

Happily, many of the biotin-rich foods we list are also strong sources of fiber, which make them great staples for people with blood sugar problems. Demonstrating this point, a Spanish research group reported that adding about an ounce of mixed nuts

into the diet for 12 weeks led to significant improvement in blood sugar control in a group of people at high risk of developing diabetes.

Skin health

Deficiency of biotin is also known to cause skin rash. This symptom occurs because biotin is necessary to build healthy fats in the skin. These fats keep the skin supple and moist, and when they are gone, the skin becomes flaky and irritated.

Back in the 1940s, a researcher demonstrated that adding high biotin foods into the diet of a lactating mother reduced symptoms of cradle cap in nursing infants. Although this research hasn't been followed up in more modern settings, we think that nursing moms could consider focusing on foods high in both biotin and omega-3 fatty acids , including salmon and eggs from pasture-raised chickens.

Summary of Food Sources

Nuts, root vegetables, and eggs are among our best sources of biotin. Each can contain more than a quarter of your daily biotin need in a single serving.

Although their contribution is not fully noted in the charts on this page, tofu, mushrooms, and many types of seeds can be biotin-rich foods. Each of these can contain close to 10% of a daily requirement per serving.

Other animal foods like milk and meat can make up another chunk of your biotin requirement. Expect 2-10% of the daily requirement from each serving in this category.

As noted above, we are still learning about the average biotin content of many important staple foods. As such, the databases that we use to score nutrient content of foods contain some large gaps when it comes to biotin. It is likely that many of the foods you see listed as not containing any biotin may actually be contributing to your total intake; we just don't know exactly how much.

The limitations of our current knowledge make it hard to do a daily diet plan that would ensure an adequate intake of biotin. Since we know that an average adult eats about double the daily requirement we believe that you don't need to worry about obtaining your daily requirement for biotin from the World's Healthiest Foods eating plan (for more on this, see the Risk of Dietary Deficiency section below).

Introduction to Nutrient Rating System Chart

In order to better help you identify foods that feature a high concentration of nutrients for the calories they contain, we created a Food Rating System. This system allows us to highlight the foods that are especially rich in particular nutrients. The following chart shows the World's Healthiest Foods that are either an excellent, very good, or good source of biotin. Next to each food name, you'll find the serving size we used to calculate the food's nutrient composition, the calories contained in the serving, the amount of biotin contained in one serving size of the food, the percent Daily Value (DV%) that this amount represents, the nutrient density that we calculated for this food and nutrient, and the rating we established in our rating system. For most of our nutrient ratings, we adopted the government standards for food labeling that are found in the U.S. Food and Drug Administration's "Reference Values for Nutrition Labeling." Read more background information and details of our rating system.

World's Healthiest Foods ranked as quality sources of biotin						
Food	Serving Size	Cals	Amount (mcg)	DRI/DV (%)	Nutrient Density	World's Healthiest Foods Rating
Tomatoes	1 cup	32.4	7.20	24	13.3	excellent
Almonds	0.25 cup	132.2	14.72	49	6.7	very good
Eggs	1 each	77.5	8.00	27	6.2	very good
Onions	1 cup	92.4	7.98	27	5.2	very good
Carrots	1 cup	50.0	6.10	20	7.3	very good
Romaine Lettuce	2 cups	16.0	1.79	6	6.7	very good
Cauliflower	1 cup	28.5	1.61	5	3.4	very good
Sweet Potato	1 cup	180.0	8.60	29	2.9	good

Oats	0.25 cup	151.7	7.80	26	3.1	good
Peanuts	0.25 cup	206.9	6.40	21	1.9	good
Walnuts	0.25 cup	196.2	5.70	19	1.7	good
Salmon	4 oz	157.6	4.54	15	1.7	good
Yogurt	1 cup	149.4	3.92	13	1.6	good
Banana	1 medium	105.0	3.07	10	1.8	good
Raspberries	1 cup	64.0	2.34	8	2.2	good
Cow's milk	4 oz	74.4	2.32	8	1.9	good
Strawberries	1 cup	46.1	1.58	5	2.1	good
Watermelon	1 cup	45.6	1.52	5	2.0	good
Grapefruit	0.50 medium	41.0	1.28	4	1.9	good
Cucumber	1 cup	15.6	0.94	3	3.6	good

World's Healthiest Foods Rating	Rule
excellent	DRI/DV>=75% OR Density>=7.6 AND DRI/DV>=10%
very good	DRI/DV>=50% OR Density>=3.4 AND DRI/DV>=5%
good	DRI/DV>=25% OR Density>=1.5 AND DRI/DV>=2.5%

Impact of Cooking, Storage and Processing

Biotin is relatively stable to most common cooking techniques. For example, when you soak and boil your beans, you'll only lose about 10% of the biotin during preparation, much less change than you'll see with most other B vitamins. The canning process is a little harder on the nutrient, leading to losses of 40-80% of the original biotin. Luckily, most of our WHFoods that provide excellent, very good, and good amounts of biotin are foods that you would be very unlikely to buy in canned form. For example, we know that many people like to purchase beans like navies, pintos, or limas in canned form, but none of these beans are foods that you would be turning to for biotin even in non-canned form.

Raw eggs contain a compound called avidin that binds and prevents absorption of biotin. Avidin has such an affinity that it doesn't just bind up the biotin in eggs, but also that found in other foods eaten with raw eggs. Because of the risk of bacterial infection from raw eggs, we don't recommend regular inclusion of them in the diet, anyway.

Risk of Dietary Deficiency

At least compared to the adequate intake recommendation standard, it appears that biotin deficiency is not very common in America. Most estimates have put average biotin intake between 30 and 40 mcg per day, or just above daily requirement.

There is a problem with these research models, however. The tables these researchers use to rate the biotin content of foods are often incomplete, so this type of analysis can systematically under estimate our daily intake. A Canadian study that more carefully analyzed each food found that average intake was closer to 60 mcg per day, double the adult daily requirement. We feel that this estimate is more representative of the dietary patterns of the Western world, and that the risk of deficiency is small.

Ensuring that your diet includes legumes, nuts, seeds, and vegetables on a regular or daily basis will be your best way to prevent a deficiency of biotin. Given that these foods are heavily represented in our World's Healthiest Foods sample menus, we believe that our diet plan is a particularly good way to ensure biotin nutrition.

Other Circumstances that Might Contribute to Deficiency

As noted above, consumption of raw egg whites can interfere with biotin absorption. This is due to a constituent called avidin which is destroyed by cooking. It is not currently clear how many raw eggs you need to eat, or for how long you'll have to eat them, to induce a deficiency state. A 2009 report concluded that one man developed symptomatic biotin deficiency from eating the equivalent of two raw egg whites daily for three months. As mentioned previously, we do not recommend intake of raw eggs on any kind of regular basis for safety reasons

A number of medications, including seizure drugs, can contribute to biotin deficiency. This may be the most common reason for biotin deficiency in the United States at this time.

Relationship with Other Nutrients

Many of the processes involving biotin also require pantothenic acid. Interestingly, these two nutrients are absorbed in the same site in the intestine. There have not been any published reports, however, of negative interaction between dietary biotin and pantothenic acid.

Risk of dietary Toxicity

There has never been a report of biotin toxicity from foods in any human or animal model that we have been able to find. Similarly, the National Academy of Sciences was unable to find any evidence for biotin toxicity, even at doses going up to nearly ten thousand times the adequate intake level recommendation. You can be confident that the amount of biotin found even in the richest food sources is not causing you any harm when these foods are consumed in everyday serving sizes.

Disease Checklist

- Hair loss
- Brittle nails
- Skin rash / seborrheic dermatitis / cradle cap
- Diabetes
- Seizures
- Pregnancy

Public Health Recommendations

In 1998, the Food and Nutrition Board of the National Academy of Sciences established a set of age-specific Adequate Intake (AI) levels for biotin. These are summarized in the chart below. These AI recommendations are used as the reference standard in the charts on this page. These AIs are as follows.

- 0-6 months: 5 mcg
- 6-12 months: 6 mcg
- 1-3 years: 8 mcg
- 4-8 years: 12 mcg
- 9-13 years: 20 mcg
- 14-18 years: 25 mcg
- 19+ years: 30 mcg
- Pregnant women: 30 mcg
- Lactating women: 35 mcg

There is no established Tolerable Upper Intake Level (UL) for biotin. Given that biotin doses several thousand times the AI have been used in medical settings, we believe it is extremely unlikely that dietary biotin presents any health risk, even in the most unusual circumstances.

The Daily Value (DV) for biotin was established by the U.S. Food and Drug Administration at 300 mcg per day per 2000 calories. It's worth noting that this DV is dramatically higher than the newer and better-researched National Academy of Sciences recommendation. Because of its newer and better-researched status, we used the National Academy of Sciences standard of 30 micrograms for adults 19 and older as our WHFoods recommended intake level for biotin.

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The World's Healthiest Foods

World's Healthiest Foods rich in calcium		
Food	**Cals**	**DRI/DV**
Tofu	164	77%
Sardines	189	35%
Sesame Seeds	206	35%
Yogurt	149	30%
Collard Greens	63	27%
Spinach	41	24%
Cheese	114	20%
Turnip Greens	29	20%
Mustard Greens	36	17%
Beet Greens	39	16%

Basic Description

Calcium is a very important mineral in human metabolism, making up about 1-2% of an adult human's body weight. In addition to its widely known role in bone structure, calcium is used to help control muscle and nerve function, as well as to manage acid/base balance in our blood stream. From this very simple description, you can see how calcium-rich foods can play a role in many aspects of your health that extend far beyond the specific area of bone health.

While the most common problem related to calcium metabolism is undoubtedly bone loss from getting too little calcium, there can be problems when intake of this nutrient gets too high as well. Excess calcium can deposit in places where it doesn't belong, including blood vessels and the kidneys (in the form of kidney stones). There is still some debate about how much of a problem this is for the average adult, but at this time, most nutrition experts agree that excess dietary calcium is very unlikely, and probably the result of a diet that is largely dependent upon dairy foods.

Dairy vs. Non-Dairy Food Sources of Calcium

Contrary to popular belief, you do not need to eat dairy foods to get the calcium you need in your meal plan. Calcium is provided by a wide variety of foods, and in order to get 1,000 milligrams per day (the Dietary Reference Intake, or DRI for women and men 19-50 years of age), you don't need cow's milk, yogurt, cheese or butter. Consider some of the following examples:

- 3.2 ounces of sardines contains more than 340 milligrams of calcium, about 2.5 times that of 4 ounces of cow's milk.
- 1 cup of steamed collards and 1 cup of cow's milk are nearly identical in terms of calcium (with collards providing 266 milligrams and cow's milk providing 276 milligrams)
- 100 calories worth of spinach provides you with twice as much calcium as 100 calories worth of yogurt
- 4 ounces of tofu, 2 TBS of sesame seeds, 1.5 cups of steamed collard greens, and 4 ounces of scallops provide you with 1,100 milligrams of calcium, or 110% DV. At the same time, these four foods only use up 394 calories, or about 22% of an 1,800-calorie meal plan.

As you can see from the examples above, many non-dairy foods can provide you with substantial amounts of calcium. Particularly helpful in this regard are green leafy vegetables like spinach, collard greens, mustard greens, turnip greens, and kale. Many fish and shellfish—including scallops and sardines—also provide concentrated amounts of calcium. Finally, a very helpful non-dairy food for boosting your calcium intake is tofu. One of the reasons for tofu's rich calcium content involves the tofu production process itself since calcium is often used to help cause precipitation of the soy milk (i.e., conversion of the soy milk into a more solid form). If you do enjoy dairy foods and want to enjoy them regularly in your meal plan, they can be a very effective way of providing you with large amounts of absorbable calcium. However, if you want to avoid dairy foods altogether, it is definitely possible for you to do so while obtaining all of the calcium you need from other foods.

Role in Health Support

Support Bone Health

At any given time, about 99% of our total body calcium stores are found in bones and teeth. This calcium plays a critical role in maintaining structural integrity of our skeleton. While calcium is the most critical nutrient to skeletal health, other nutrients provide important support to help absorb and use calcium in the bones. These nutrients include vitamin D, vitamin K, and magnesium.

It may sound counter-intuitive, but bone is very metabolically active tissue, with bone being built and broken down constantly. When our dietary calcium levels are too low, we pull calcium from the bones to keep the blood levels close to constant. As long as we correct this imbalance more days than not, this borrowing and returning process works very well. But if we do more borrowing from than replenishing to our calcium stores, bone can become dangerously weak.

In some sense, this gives us flexibility with our diets. In other words, we do not have to get a full supply of calcium each day, as long as we reach our goals most days. As long as your diet contains a wide variety of the foods on our World's Healthiest Foods list, we believe that your calcium intake should be sufficient to maintain strong bones.

Note that we tend to think of low bone mineral density, or osteoporosis, as a disease of the elderly. While it is true that the bone fractures that occur tend to be in older adults, the damage that leads to osteoporosis can start very early with poor dietary choices during childhood and adolescence. In fact, the pre-teen and teen years are arguably the most critical time to meet dietary calcium needs, as nearly 40% of total adult bone mass is established between the ages of 10 and 15 years.

While it is clear that there is a level of dietary calcium below which bone integrity is compromised, it is not at all clear that lack of dairy products (or dietary calcium in general) is associated with increased risk of osteoporosis in all populations. In fact, most of the evidence for the protective effect of dairy has been in children and adolescents. In adults, however, recent research reviews have been unable to show a significant protective effect of dietary or total (e.g., diet plus supplements) calcium intake against bone loss.

Acid/Alkaline Balance

Calcium is an absolutely critical nutrient in regulating acid/alkaline balance (called pH) in the blood. When blood pH starts getting low (down to 7.35 from a baseline of 7.4), calcium starts getting released from the bones to bring acid/base balance back into balance. A complex set of hormonal interactions manages this process, and it is tightly regulated. The pH of blood is of critical importance to sustain life, and controls processes as varied as breathing rate and the ability to transport oxygen in blood cells.

While this process requires no conscious attention, it is very important toward understanding the risk of bone loss with aging. Diet and lifestyle choices that drive more of this leeching of calcium from the bones will increase need for dietary calcium over time.

Because the rate of calcium loss from the bones varies so much from individual to individual, determining the average calcium daily need for the population is a difficult process. Perhaps the easiest way to understand this problem is to think about calcium stores as a bank account, so that when calcium in is equal or greater than calcium out, your balance stays in the black. But when calcium loss exceeds the intake, even by small amounts, you'll end up in deficit. Note that by this math, children and adolescents are going to need to do more than just achieve balance, as they may add as much as 400 mg of calcium to growing bones each day.

Note that acid/alkaline balance of the diet has become a hot topic in the nutrition and physical training cultures. We believe that outside of the effect of balance of the key minerals (calcium, magnesium, sodium, and potassium), focusing on acid/alkaline balance of foods is neither necessary nor beneficial. Most healthy diets tend to be on the alkaline side—although people's definitions of acid/alkaline foods vary from source to source—but that this is more because these healthy diets tend to be rich in plant foods that act as good sources of important minerals.

As we'll discuss below, foods that are heavily salted tend to lead to loss of calcium in the urine. Because of this, it may be helpful to focus more on sources of calcium that contain less sodium (e.g., lightly cooked greens versus types of cheeses that require large amounts of salt in their production).

Muscle and Nerve Function

When a muscle cell receives a signal from nerves telling it to fire that cell responds by allowing a flood of calcium into the cell. This abrupt change leads to a cascade of activity and has the effect of making the muscle cell contract. If calcium levels are abnormal, either too high or too low, this process can be interrupted, which will lead to muscle spasm.

Regulation of the balance of calcium inside and outside of nerve cells is involved in helping to control the flow of sodium in and out. This sodium flow is how the nerves conduct signals to and from the brain. Like the muscles, abnormal calcium concentrations in the blood stream may adversely affect the ability of the nerves to transmit signals.

Because our bodies have such extensive calcium stores to draw upon to keep blood levels constant, it is very unlikely that simple dietary deficiencies would contribute to problems in these activities for most people. The combination of organ disease (particularly kidney disease) and/or hormonal problems (particularly vitamin D or parathyroid abnormalities) plus poor or excessive calcium intake may be enough to cause symptomatic imbalances, however.

Summary of Food Sources

Currently, an estimated 72% of calcium in an average American's diet comes from dairy foods. Vegetables (7%), grains (5%), legumes (4%), and meat/fish (3%) also contribute to total calcium intake. Although fortified foods, including cereals, juices, and non-dairy milks are widely available and utilized, it is not currently known how much they contribute to dietary calcium nationwide.

According to the 2010 USDA Dietary Guidelines for Americans, people older than 9 years old have 3 cups of milk per day. This would provide nearly 900 mg of calcium; assuming that some calcium comes from other foods, this would likely be enough calcium for most people.

However, many people by choice or medical need avoid dairy in their diet. For those who do not follow a vegan diet, canned sardines or salmon may be an easy way to replace a large portion of dairy calcium. Tofu, bok choy, and turnip greens are examples of good vegan calcium sources.

Calcium can be a relatively difficult mineral to absorb from foods. Depending on the type of calcium, and more importantly other accessory nutrients present in the meal, calcium absorption can vary greater than ten-fold from food to food.

The most important contributors to this variability are the two nutrients (sometimes referred to as anti-nutrients) phytate and oxalate. Both are able to bind calcium tightly, reducing its absorption. Both are also nearly exclusively found in plant foods, with much variation from source to source.

In a practical sense, this means that having foods rich in phytate and oxalate at the same time as your best calcium sources may interfere with absorption. But to put this point in perspective, people who eat largely plant based diets (i.e., vegetarians) do not have increased risk of osteoporosis, which you would predict if these plant-based nutrients were impairing calcium absorption to a clinically relevant degree. So, while you do not absorb calcium as efficiently from non-dairy foods, this does not make them irrelevant or counter-productive. We recommend several servings of calcium-rich vegetables throughout the day to maximize availability of this nutrient.

As described earlier, many processed food manufacturers add calcium to packaged foods including non-dairy milks, fruit juices, grain-based cereals, and other products. We do not recommend that you rely on these calcium-fortified foods to meet your calcium needs. For more details about fortification of foods with calcium, please see our section Impact of Cooking, Storage and Processing.

Introduction to Nutrient Rating System Chart

In order to better help you identify foods that feature a high concentration of nutrients for the calories they contain, we created a Food Rating System. This system allows us to highlight the foods that are especially rich in particular nutrients. The following chart shows the World's Healthiest Foods that are either an excellent, very good, or good source of calcium. Next to each food name, you'll find the serving size we used to calculate the food's nutrient composition, the calories contained in the serving, the amount of calcium contained in one serving size of the food, the percent Daily Value (DV%) that this amount represents, the nutrient density that we calculated for this food and nutrient, and the rating we established in our rating system. For most of our nutrient ratings, we adopted the government standards for food labeling that are found in the U.S. Food and Drug Administration's "Reference Values for Nutrition Labeling." Read more background information and details of our rating system.

World's Healthiest Foods ranked as quality sources of calcium						
Food	Serving Size	Cals	Amount (mg)	DRI/DV (%)	Nutrient Density	World's Healthiest Foods Rating
Tofu	4 oz	164.4	774.51	77	8.5	excellent

Collard Greens	1 cup	62.7	267.90	27	7.7	excellent
Spinach	1 cup	41.4	244.80	24	10.6	excellent
Turnip Greens	1 cup	28.8	197.28	20	12.3	excellent
Mustard Greens	1 cup	36.4	165.20	17	8.2	excellent
Beet Greens	1 cup	38.9	164.16	16	7.6	excellent
Bok Choy	1 cup	20.4	158.10	16	14.0	excellent
Yogurt	1 cup	149.4	296.45	30	3.6	very good
Swiss Chard	1 cup	35.0	101.50	10	5.2	very good
Kale	1 cup	36.4	93.60	9	4.6	very good
Cinnamon	2 tsp	12.8	52.10	5	7.3	very good
Sesame Seeds	0.25 cup	206.3	351.00	35	3.1	good
Sardines	3.20 oz	188.7	346.54	35	3.3	good
Cheese	1 oz	114.2	204.40	20	3.2	good
Cow's milk	4 oz	74.4	137.86	14	3.3	good
Cabbage	1 cup	43.5	63.00	6	2.6	good
Broccoli	1 cup	54.6	62.40	6	2.1	good
Brussels Sprouts	1 cup	56.2	56.16	6	1.8	good
Green Beans	1 cup	43.8	55.00	6	2.3	good
Oranges	1 medium	61.6	52.40	5	1.5	good
Summer Squash	1 cup	36.0	48.60	5	2.4	good
Fennel	1 cup	27.0	42.63	4	2.8	good
Parsley	0.50 cup	10.9	41.95	4	6.9	good
Asparagus	1 cup	39.6	41.40	4	1.9	good
Celery	1 cup	16.2	40.40	4	4.5	good
Cumin	2 tsp	15.8	39.10	4	4.5	good
Basil	0.50 cup	4.9	37.52	4	13.8	good
Garlic	6 cloves	26.8	32.58	3	2.2	good
Oregano	2 tsp	5.3	31.94	3	10.8	good
Leeks	1 cup	32.2	31.20	3	1.7	good
Romaine Lettuce	2 cups	16.0	31.02	3	3.5	good
Cloves	2 tsp	11.5	26.54	3	4.2	good
Black Pepper	2 tsp	14.6	25.69	3	3.2	good

World's Healthiest Foods Rating	Rule
excellent	DRI/DV>=75% OR Density>=7.6 AND DRI/DV>=10%
very good	DRI/DV>=50% OR Density>=3.4 AND DRI/DV>=5%
good	DRI/DV>=25% OR Density>=1.5 AND DRI/DV>=2.5%

Impact of Cooking, Storage and Processing

Calcium content of foods is remarkably stable. Calcium does not degrade or leech out of foods as they are stored, and there does not appear to be any major change in bioavailability of calcium over the shelf life of the best food sources.

Some calcium-containing foods also contain two substances that have a long history of controversy in scientific research - oxalic acid and phytic acid. (These substances can also be referred to as "oxalates" and "phytates.") Both oxalates and phytates can bind together with calcium and other minerals, and this binding process shows up in some studies as lowering the amount of calcium that gets absorbed from our digestive tract up into our body. However, our digestive processes are never simple, and other studies show people to be fully healthy in terms of their calcium nourishment even when their overall meal plan contains many foods high in oxalates and phytates.

As a general rule, we do not think that you need to avoid oxalate or phytate-containing foods in your meal plan even if your primary goal is to improve your calcium intake. Boiling a high-oxalate food like spinach can often reduce its oxalate content by about 10%. This result may be a good thing if you are focusing on calcium nourishment, but once again, we do not think that this issue should be treated as a key factor in your decision-making process about your meal plan or consumption of raw versus cooked spinach.

Phytates in food are often reduced by sprouting, and if you enjoy sprouted seeds, beans, nuts, legumes or grains, you may get some improved mineral nourishment (including calcium nourishment) from these foods in sprouted versus non-sprouted form. Fermenting can also lower a food's phytate content, particularly if the bacteria and other micro-organisms used in fermentation contain phytase enzymes that can break down phytates. For this reason, you may get some increased calcium benefits from consumption of calcium-containing, traditionally fermented foods including Tofu, Yogurt, grass-fed and sauerkraut.

Note that if you simply look at food charts of calcium content, it may look like cooking foods increases calcium levels. This is just an artifact, however, an only reflects the loss of water content, which in turn concentrates the same amount of calcium in a smaller volume.

Many processed foods add calcium in the manufacturing process. Some undergo a process called fortification, or the adding of calcium salts that were not originally there. Non-dairy milks, juices, and breakfast cereals all are commonly fortified with calcium.

Another specific example of calcium being added in the processing of food is in the manufacture of tofu. Many tofu products use calcium sulfate to precipitate the solid protein-rich soy as curds from solution. Other tofu products use sodium (referred to as nigari) to coagulate the solid product. Choosing tofu made with calcium sulfate comes close to doubling the amount of available calcium per serving.

Risk of Dietary Deficiency

Unlike most other nutrients where deficiency is defined by an amount below which a deficiency syndrome emerges, calcium deficiency has been defined as an intake amount below that required to prevent net daily calcium loss. For most adults, this amount is 300-400 milligram of absorbable calcium per day. Because dairy calcium is absorbed at about 30% of total calcium (with most vegetable sources close behind in the low-to-mid-20% range), this means that amounts around 900-1,200 milligram per day are enough to offset the daily loss of this mineral.

Because children and adolescents are actively depositing new bone at a rapid clip, just getting enough calcium to offset losses is not enough. Depending on the age of the child, up to an extra 400 mg of dietary calcium may be necessary to keep up with bone growth. See the section on public health recommendations below for age specific intake recommendations.

Absorption of dietary calcium becomes progressively less efficient with age, and we absorb about 0.2% less per year after age 40. This may not sound like much, by the time we reach our 60s and 70s, this small and incremental change is large enough that our daily calcium requirement needs to increase. Given that this is also an age range where bone mineral density loss can occur quickly, calcium nutrition is arguably nearly as important in the post-menopausal and elderly populations as it is in children and adolescents.

Americans very frequently fail to get the daily recommended intake of calcium. Women, in particular, fail to achieve the Recommended Dietary Allowance (RDA) on average in every age group older than 8 years old. Less than 15% of adolescent girls and less than 10% of elderly women (the populations who should be most careful about calcium nutrition) meet daily requirement thresholds through their diets.

People who don't regularly consume dairy products are the most likely to have the most difficulty achieving a positive calcium status; this may because the average U.S. adult doesn't routinely eat foods like fresh greens and tofu, which are also concentrated calcium sources. The average American gets about 1.8 cups of the recommended 3 cups of dairy products per day, but there is a great deal of individual variability in this intake estimate.

Generally speaking, moving from a standard American processed food diet toward the World's Healthiest Foods style of eating will spread out your calcium intake among a wide variety of foods that contain a moderate amount of calcium, rather than relying exclusively on the frequent intake of dairy products to meet your needs.

Other Circumstances that Might Contribute to Deficiency

Even if your diet contains enough calcium by the DRI standard, it is still possible to be in calcium deficit, as many factors control calcium absorption, deposition, and excretion. These factors would be those that can be identified by a healthcare practitioner. By paying attention to these factors, it may be possible to affect your net calcium balance by keeping the mineral around longer, as well as maintaining plenty of daily supply.

One of the biggest contributors to calcium nutrition is vitamin D. Low levels of vitamin D can impair absorption of calcium from the intestines. Secondarily, low levels of vitamin D can impair the ability of the kidneys and bone to maintain normal circulating calcium levels. Because dietary vitamin D levels tend to be low in the population, this ends up being a potential amplifier of problems related to low calcium intake.

Relationship with Other Nutrients

Many foods that contain calcium also contain vitamin D. For example, two of our top calcium-containing WHFoods (sardines and cow's milk) also belong to our top vitamin D-containing WHFoods. This overlap between calcium and vitamin D in whole, natural foods is a good thing, and it's no accident. These two nutrients clearly work together in metabolism. For example, as described earlier, vitamin D is needed to move calcium from our digestive tract up into our body. Because the balance of calcium and vitamin D in whole, natural foods is a healthy one, it's best to rely on these foods as your source for both nutrients, and there is no need for you to worry about your calcium and vitamin D balance if you are following a meal plan that is primarily composed of whole, natural foods.

However, very high dose supplementation with either calcium, vitamin D, or both may result in a balance for these two nutrients that is not optimal. If you are taking daily vitamin D supplements well above the Tolerable Upper Limit for vitamin D as set by the National Academy of Sciences at 4,000IU for adults, and/or calcium supplements well above the Tolerable Upper Limit for adults ranging from 2,000-3,000 mg, we recommend that you talk with your healthcare provider about the best supplementation plan to follow, so that you can be sure to get an optimal and safe ratio of these two nutrients.

Calcium can compete with many other minerals for absorption, most importantly magnesium, zinc, and iron. At dietary intakes of up to 1,500 mg per day, however, this interaction does not appear to be clinically important. If you routinely eat more than 1,500 mg of dietary calcium per day, you may need to increase your daily iron and zinc supply accordingly.

Diets high in sodium increase the loss of calcium in the urine. At DRI intakes and above of calcium, a goal most Americans fail to achieve, our kidneys are believed to be able to offset this calcium loss and maintain bone density. Since DRI values are based in part upon managing dietary intake to offset urinary loss, this should not be a surprise. What is not currently known is whether keeping dietary sodium under control—average Americans get more than double the recommended amount of sodium daily—would allow for calcium balance at a smaller average intake of calcium than the DRI.

The size of the effect of reducing dietary sodium on bone loss is not just an academic concern. The sample menus on our site range between 1,100 and 2,400 mg of sodium per day, whereas standard American diets average between 4,000 and 5,000 mg per day. Reducing dietary sodium in this way would be expected to keep an extra 20 or so mg of extra calcium in the bones each day.

Dietary protein has a complex relationship with calcium balance. On the positive side, diets high in protein increase stomach acid production, potentially optimizing intestinal absorption of calcium. On the other hand, dietary protein also increases the loss of calcium in the urine. At dietary protein intakes that most Americans achieve, these countervailing forces very likely balance each other out, leaving no overall effect. At extremes of protein intake, particularly protein calorie malnutrition, calcium balance can be disturbed.

Alcohol leads to modest loss of calcium in the urine, which is marginal for most adults. For example, giving adult men a daily alcohol dose equivalent to just over four shots of liquor was not associated with significant change in urine calcium loss. Long-term alcohol abuse, however, is a risk factor for bone loss, likely by a mechanism that involves the hormones that control calcium blood levels.

Even though the phytate found in plant foods may impair calcium absorption, it does not appear that diets high in phytate associate with loss of bone density. In fact, the opposite is true—diets high in phytate have been associated with improvements in bone mineral density. This is good news since plant-based eating plans like those featured here are rich in phytic acid. While noting that some other sources disagree—particularly advocates of the paleolithic diet strategies—we do not recommend restricting phytate-rich foods to improve calcium absorption under any circumstances.

Risk of dietary Toxicity

The National Academy of Sciences (NAS) in its 2010 public health recommendations for calcium noted that excessive amounts of dietary calcium are "difficult, not impossible" to achieve in normal healthy adults. In a nation where as many as 90% of at-risk demographic groups (e.g., adolescents, elderly women) fail to reach target intakes of calcium, worrying about calcium excess seems like a misplaced effort to us.

However, to get a better understanding in this area, let's take the NAS guidelines for calcium and see what level of food intake would constitute too much. In its 2010 public health recommendations for calcium, the NAS established the following maximum recommended amounts (which they call Tolerable Upper Intake Levels, or ULs) for this mineral:

Tolerable Upper Intake Levels (ULs) for Calcium:

- 0-6 months: 1,000 mg
- 6-12 months: 1,500 mg
- 1-3 years: 2,500 mg
- 4-8 years: 2,500 mg
- 9-13 years: 3,000 mg
- 14-18 years: 3,000 mg
- 19-30 years: 2,500 mg
- 31-50 years: 2,500 mg
- 51+ years: 2,000 mg
- Pregnant and lactating women (younger than 18 years): 3,000 mg
- Pregnant and lactating women (older than 18 years): 2,500 mg

In order for a middle-aged person to exceed this 2,500 milligram limit on calcium intake, that person would need to eat about 10 cups of spinach or collard greens (two of our "excellent" WHFoods sources of calcium). Similarly, a person would need to consume about 6 cups of yogurt to go over this amount.

There is a condition called milk-alkali syndrome where serious dehydration can occur related to excessive calcium intake. This is almost always caused by supplements of calcium (or antacids medications containing calcium), although it is known to be a risk at intake of dietary calcium above 2,000 mg per day. . As noted earlier, however, intake of 2,000 milligrams from a day's food is generally unlikely. Persons with existing kidney-related problems or special risk of such problems fall into a special category here. Under these circumstances, we recommend consultation with a healthcare provider to determine the ideal maximum amount of dietary calcium.

Because we have such elaborate hormonal control of our calcium levels, it is much more likely that calcium excess events are due to a medical condition than due to eating too many calcium-rich foods.

Disease Checklist

- Osteoporosis / bone health
- High blood pressure (hypertension)
- High cholesterol (hyperlipidemia)
- Gastroesophageal Reflux Disease (GERD)
- Pregnancy and lactation
- Preeclampsia

Public Health Recommendations

In 2010, the National Academy of Sciences released Dietary Reference Intake (DRI) updates that included Recommended Dietary Allowances (RDA) for age and gender specific calcium intake goals. These RDAs are as follows.

- 0-6 months: 200 mg
- 6-12 months: 260 mg
- 1-3 years: 700 mg
- 4-8 years: 1,000 mg
- 9-13 years: 1,300 mg
- 14-18 years: 1,300 mg
- 19-30 years: 1,000 mg
- 31-50 years: 1,000 mg
- 51-70 years, female: 1,200 mg

- 51-70 years, male: 1,000 mg
- 70+ years: 1,200 mg
- Pregnant or lactating women, 14-18 years: 1,300 mg
- Pregnant or lactating women, 19-50 years: 1,300 mg

The upper limit (UL) of calcium according to the DRI recommendations varies by age and gender. They are as follows.

- 0-6 months: 1,000 mg
- 6-12 months: 1,500 mg
- 1-3 years: 2,500 mg
- 4-8 years: 2,500 mg
- 9-13 years: 3,000 mg
- 14-18 years: 3,000 mg
- 19-30 years: 2,500 mg
- 31-50 years: 2,500 mg
- 51-70 years, female: 2,000 mg
- 51-70 years, male: 2,000 mg
- 70+ years: 2,0000 mg
- Pregnant or lactating women, 14-18 years: 3,000 mg
- Pregnant or lactating women, 19-50 years: 2,500 mg

Please note that as we cited above, it is nearly impossible to reach this amount of calcium without heavily leaning on supplements or fortified foods.

The Dietary Reference Intake (DRI) for calcium as established by the National Academy of Sciences for 19-50 year-old women is 1,000 milligrams, and that is the amount we chose as our WHFoods standard. In this particular case, 1,000 milligrams is also the Daily Value (DV) established by the U.S. Food and Drug Administration (FDA).

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The World's Healthiest Foods

World's Healthiest Foods rich in choline		
Food	Cals	DRI/DV
Shrimp	135	36%
Eggs	78	35%
Scallops	126	30%
Chicken	187	23%
Turkey	167	22%
Tuna	147	21%
Cod	96	21%
Salmon	158	19%
Beef	175	17%
Collard Greens	63	17%

Basic Description

Choline is one of the newest nutrients to be added to the list of human vitamins. It was only added to the list of required nutrients by the National Academy of Sciences (NAS) in 1998. While the NAS does not officially recognize choline as a vitamin specifically belonging to the B-complex family of vitamins, it is officially recognized as a required nutrient that you need in your everyday meal plan.

It was once believed that we made enough choline in our bodies from other nutrients to meet our need for this important substance. More recent research using choline-depleted diets has demonstrated that we really do require some outside help from our food to keep our bodies running well.

Now that we have established a need for choline, the next question we have to answer is how much of it do we require each day. This is still an open question in the nutrition world. We do know, however, that the current National Academy of Sciences standards listed below in the Public Health Recommendations section are a pretty good place to start.

Luckily, choline is widely distributed throughout different types of foods. Given the focus on variety, the World's Healthiest Foods recipes should make it pretty easy to get the choline you need. We detail below in both the Summary of Food Sources and Risk of Dietary Deficiency sections how to carve a path to the daily requirements using recipes and foods from our site.

We list eggs as an excellent source of choline. But even if you don't do well with eggs and choose to avoid them in your diet, we also have 10 very good and 15 good choline sources. This should give you plenty of choices to ensure a strong intake.

Role in Health Support

Methylation

Many of the signaling processes in the human body involve passing a methyl group—sort of like the biochemical version of a penny—from place to place. This is one of the most basic processes of life, and no cellular organism could survive without the process of methylation. Building DNA, exchanging signals in the brain, and detoxification in your liver are just some of the important processes dependent on methylation. Deficits in methylation have been linked to memory loss and cardiovascular disease.

Perhaps speaking to the central importance of methylation in normal body function, there are a number of different nutrients that are important for this process to work smoothly. The most important are folate and its partners vitamins B6 and B12.

You can think about choline as a key partner in this process. For example, when folate is not available in sufficient amounts to assure adequate methylation, choline can provide its assistance and help assure that methylation continues.

Membrane Structure

Choline is an essential nutrient in the production of phosphatidylcholine, one of the most important structural building blocks of a living cell. Its unique soap-like structure helps to keep the membrane fluid, yet mostly impermeable.

Given importance of phosphatidylcholine to all cellular forms, it's not surprising that we find choline so widespread in different foods. In most diets, phophatidylcholine is the single most common form of choline provided by foods.

Nervous System Activity

Choline is the backbone of a nervous system signal molecule—or neurotransmitter—called acetylcholine. The importance of acetylcholine cannot be overstated. The part of your nervous system that runs your heart and keeps your intestines moving along runs largely on acetylcholine. Similarly, any muscle you move requires a signal of acetylcholine to tell it to contract.

Like the action of the heart itself, you really don't need to think or worry about this action of choline. Even in medically supervised situations where people eat diets bizarrely restricted in choline, we don't see these activities break down.

Summary of Food Sources

Choline is widely available in most things you eat. It is found in plant and animal foods, and in whole as well as processed foods. (Of course, we always recommend whole over processed foods.)

If you have already heard people talk about foods that are high in choline, the one food that you are mostly likely to have heard them mention is eggs. You'll get one-quarter to one-third of your daily intake requirement from a single egg (this range is gender-dependent given that males and females are noted to have different optimal intake levels). Since over 99% of an egg's choline is located in the yolk, the whites alone aren't very helpful for boosting your choline intake.

Of course, we include eggs as one of our 10 Most Controversial Foods, and we know that some people choose to avoid them. If you fall into that category, but still incorporate other animal foods in your meal plan, you still have many good sources to choose from. Given our top 8 WHFoods rich in choline, all 8 are animal foods.

However, even if you avoid all animal foods in your meal plan, you can still get good and very good amounts from many plant foods. Vegetables are by far your best plant sources of choline! At least 15 WHFoods rank as good or very good sources of choline in our rating system. Your most nutrient-rich options here include collard greens, Brussels sprouts, broccoli, Swiss chard, cauliflower, and asparagus. One serving of any vegetable in this list will provide you with over 10% of the WHFoods recommended daily intake for choline. Also, for anyone who enjoys fish in their meal plan but avoids land animal foods, three of our WHFoods seafoods—shrimp, scallops, and cod—qualify as very good sources of choline.

An average American gets about 100 mg of extra choline per day from food additives. The most common of these is soy lecithin, which is widely used as an emulsifying agent. These emulsifying agents help to keep oil- and water-soluble ingredients from separating in packaged foods. At WHFoods, we recommend 425 mg of choline each day, and so you can see how this extra choline from food additives represents about one-fourth of that amount. So while it can be helpful to you in meeting your choline requirement, you are still going to need a lot more choline from your food. (Also, it is very easy to see how this average amount of choline from food additives is not likely to put you into the "excess" category of 3500 mg (3.5 grams) for choline even if your meal plan contains numerous choline-rich foods.

Introduction to Nutrient Rating System Chart

In order to better help you identify foods that feature a high concentration of nutrients for the calories they contain, we created a Food Rating System. This system allows us to highlight the foods that are especially rich in particular nutrients. The following chart shows the World's Healthiest Foods that are either an excellent, very good, or good source of choline. Next to each food name, you'll find the serving size we used to calculate the food's nutrient composition, the calories contained in the serving, the amount of choline contained in one serving size of the food, the percent Daily Value (DV%) that this amount represents, the nutrient density that we calculated for this food and nutrient, and the rating we established in our rating system. For most of our nutrient ratings, we adopted the government standards for food labeling that are found in the U.S. Food and Drug Administration's "Reference Values for Nutrition Labeling." Read more background information and details of our rating system.

World's Healthiest Foods ranked as quality sources of choline						
	Serving		Amount	DRI/DV	Nutrient	World's Healthiest

Food	Size	Cals	(mg)	(%)	Density	Foods Rating
Eggs	1 each	77.5	146.90	35	8.0	excellent
Shrimp	4 oz	134.9	153.54	36	4.8	very good
Scallops	4 oz	125.9	125.53	30	4.2	very good
Cod	4 oz	96.4	90.38	21	4.0	very good
Collard Greens	1 cup	62.7	72.96	17	4.9	very good
Brussels Sprouts	1 cup	56.2	63.34	15	4.8	very good
Broccoli	1 cup	54.6	62.56	15	4.9	very good
Swiss Chard	1 cup	35.0	50.23	12	6.1	very good
Cauliflower	1 cup	28.5	48.48	11	7.2	very good
Asparagus	1 cup	39.6	46.98	11	5.0	very good
Spinach	1 cup	41.4	35.46	8	3.6	very good
Chicken	4 oz	187.1	96.73	23	2.2	good
Turkey	4 oz	166.7	94.57	22	2.4	good
Tuna	4 oz	147.4	88.00	21	2.5	good
Salmon	4 oz	157.6	81.65	19	2.2	good
Beef	4 oz	175.0	73.82	17	1.8	good
Sardines	3.20 oz	188.7	68.04	16	1.5	good
Green Peas	1 cup	115.7	40.91	10	1.5	good
Cabbage	1 cup	43.5	32.10	8	3.1	good
Mushrooms, Shiitake	0.50 cup	40.6	26.68	6	2.8	good
Green Beans	1 cup	43.8	21.13	5	2.0	good
Bok Choy	1 cup	20.4	20.57	5	4.3	good
Mushrooms, Crimini	1 cup	15.8	15.91	4	4.3	good
Summer Squash	1 cup	36.0	14.22	3	1.7	good
Miso	1 TBS	34.2	12.41	3	1.5	good
Tomatoes	1 cup	32.4	12.06	3	1.6	good

World's Healthiest Foods Rating	Rule
excellent	DRI/DV>=75% OR Density>=7.6 AND DRI/DV>=10%
very good	DRI/DV>=50% OR Density>=3.4 AND DRI/DV>=5%
good	DRI/DV>=25% OR Density>=1.5 AND DRI/DV>=2.5%

Impact of Cooking, Storage and Processing

Given the relatively small amount of research on choline, we do not have as strong a body of evidence to demonstrate the magnitude of changes with cooking or storage. Still, at this time, we can say that choline appears to be a fairly stable nutrient to heat and storage compared with many other vitamins. We do not currently believe that you need to alter your food storage habits or cooking techniques in order to obtain substantial amounts of choline from your foods.

Risk of Dietary Deficiency

Our knowledge of exactly how much choline an average person eats in a day is limited by an incomplete understanding of how much of it is found in commonly eaten foods. Still, researchers have published ballpark estimates of between 700 and 1000 mg of choline as an average American adult intake. This amount clearly exceeds our WHFoods recommendation of 425 mg per day.

Let's go through an example of a daily meal plan that is rich in choline. We can start the morning with Poached Eggs Over Spinach and Mushrooms. This will provide at least 350 mg of choline, well over half of the WHFoods recommended daily amount.

At lunch, we'll have Italian Navy Bean Soup and some cantaloupe. This light plant-based meal will have less choline than breakfast and dinner but will still make a substantial contribution of over 100 mg, or close to a quarter of the daily requirement.

For dinner, we'll enjoy the 3-Minute Scallops with a side of steamed broccoli. This provides at least 200 mg of choline, which adds up to about 650 mg and takes us well beyond our 425 mg WHFoods daily requirement.

Note that each of these meals contains "at least" a certain amount of choline because some of the ingredients have not been formally assessed for choline content. While this daily menu contains plenty of choline, it may actually contain even more than we are aware.

Other Circumstances that Might Contribute to Deficiency

The only circumstance documented in research studies under which symptoms clearly related to choline deficiency occurs is in prolonged tube feeding. Needless to say, prolonged tube feeding is a medical necessity in certain situations but unrelated to our everyday food choices. .

Relationship with Other Nutrients

As noted above, the process of methylation is very important for the brain, for cancer prevention, and for reproduction, among other things. Choline is one of many methyl donors in the body, and as such, it can help fill in when the levels of other important methylators like folate and S-adenosylmethionine get low. Pantothenic acid (also referred to as vitamin B5) is necessary for the production of acetylcholine from choline in nerves. Luckily, neither one of these nutrients is commonly deficient in the U.S. diet.

Risk of dietary Toxicity

At intake amounts exceeding several grams per day, choline can cause significant drops in blood pressure. Also, intake of excessive choline can cause a fishy body odor due to a metabolite formed during excretion. The National Academy of Sciences has established 3.5 grams per day as aTolerable Upper Intake Level (UL) for choline. This amount would almost certainly require intake of choline supplements and would be highly unlikely to be provided by food intake alone.

Disease Checklist

- Pregnancy support
- High homocysteine
- Depression
- Bipolar disorder
- Memory loss / cognitive decline
- Gallstones
- High cholesterol

Public Health Recommendations

In 1998, the National Academy of Sciences (NAS) established Adequate Intake (AI) standards for choline. These AIs are as follows:

- 0-6 months: 125 mg
- 6-12 months: 150 mg
- 1-3 years: 200 mg
- 4-8 years: 250 mg
- 9-13 years: 375 years
- 14-18 years, female: 400
- 14-19 years, male: 550 mg
- 19+ years, female: 425 mg
- 19+ years, male: 550 mg
- Pregnant women: 450 mg
- Lactating women: 550 mg

The NAS also established a Tolerable Upper Intake Level (UL) of 3.5 grams per day for most adults. While it would be possible to eat more than this occasionally, it would be very hard to do. None of the reported cases of toxicity related to high doses of choline cited by the FNB were from dietary intake alone.

For our WHFoods recommended daily amount of choline, we chose the Dietary Reference Intake (DRI) standard of 425 milligrams for women 19 and older. You can click here for more information about our rating system and nutrient recommendations.

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The World's Healthiest Foods

World's Healthiest Foods rich in chromium		
Food	Cals	DRI/DV
Broccoli	55	53%
Barley	217	23%
Oats	152	15%
Green Beans	44	6%
Tomatoes	32	4%
Romaine Lettuce	16	4%
Black Pepper	15	3%

Basic Description

You might think by looking at the chart above that chromium is a mineral mostly missing in the food supply. However, it would definitely be wrong to draw this conclusion. Chromium is provided by every food group—including vegetables, fruits, grains, legumes, nuts/seeds, seafood, meats and dairy—so it is definitely not a missing mineral in our foods. However, chromium is present in many foods in very small amounts (1-2 micrograms or less). In fact, our rating system only calculated one excellent source of chromium. So we think about this mineral as one that you obtain by eating an overall healthy diet rather than any specific foods. It's also important to note that the chromium content of food has been inadequately measured by food scientists. Research journals typically show less than 10 total measurements for chromium in any particular food, and many of these measurements show little consistency. As a result, we know that many foods contain small amounts of chromium, but we are still not sure about exact amounts or how amounts might vary under different circumstances. Once again, these factors shift the focus onto an overall healthy diet when evaluating intake of chromium.

Foods rich in chromium, specifically brewer's yeast, have been used to help balance blood sugar since the time of the Civil War. In the 1950s, researchers discovered the role of chromium in blood sugar control, a role we describe below in the Role in Health Support section.

Among the foods where the chromium content is noted, we have broccoli listed as an excellent source. We also list six foods as good sources. These foods are barley, oats, green beans, tomatoes, romaine lettuce, and black pepper.

While we don't know the exact chromium content of many of the World's Healthiest Foods, it appears that our strategy of eating—based around minimally processed and plant-rich meals with liberal use of spices—would be expected to ensure a consistent supply of this mineral.

Role in Health Support

Blood Sugar Control

A key role for chromium in the body is related to control of blood sugar. There is a signal molecule called low-molecular weight chromium binding substance (LMWCr) involved in blood sugar control. (You may also hear this molecule being referred to as chromodulin.) Although it has a long name, LMWCr it is a tiny molecule, built from just a few amino acids.

This LMWCr binds next to the place where insulin, a key hormone that controls blood sugar, interacts with the outside of a cell. Its role is to increase the strength of the signal that insulin sends, helping to drive blood sugar into cells more quickly after a meal. (It is also worth noting here that LMWCr is a very specifically defined molecule with a specifically defined metabolic role. Prior to discovery of LMWCr, a much less clearly defined molecule called glucose tolerance factor, or GTF, had been the subject of much interest in nutrition and was typically thought to involve a combination of chromium, vitamin B3, and select amino acids. However, unlike LMWCr, GTF remains to be specifically defined or universally accepted by researchers.)

We have seen evidence of chromium deficiency leading to abnormally high blood sugar as well as evidence that restoring chromium supply back toward normal or higher can enhance blood sugar control even in some people with diabetes. Research studies of this kind underscore the importance of LMWCr and chromium for blood sugar balance.

Healthy diets like the World's Healthiest Foods eating plan tend to be associated with low risk for type 2 diabetes. Strong chromium nutrition is one of many reasons this would be true.

Note that some of our chromium-rich World's Healthiest Foods have additional ways that they help balance blood sugar. Cinnamon and sweet potatoes would be a couple examples of these. Here's a tasty recipe—Sweet Potatoes with Ginger and Cinnamon—that combines them.

Summary of Food Sources

Because the amounts of chromium in foods are quite small, researchers have struggled to clearly quantify dietary chromium intake in the same way we can with other nutrients. However, based on our overall understanding of food and nutrients, we are confident that many of the World's Healthiest Foods contain chromium, even if the database we use to determine content is incomplete. Broccoli, which does have a measured value for chromium in our database, contains about half of your daily requirement per serving and ranks as an excellent source of this nutrient. In the vegetable group, tomatoes, green beans, and romaine lettuce rank as good sources.

Several whole grains, including oats and barley, rank as good sources of chromium in our rating system. Other clearly-established food sources of chromium (but not ranked in our system as good, very good, or excellent sources) include fruits like apples and bananas, meats like chicken, grains like brown rice, and dairy products like eggs and cow's milk. Herbs and spices also provide measurable amounts of chromium, with black pepper ranking as a good source in our rating system. As described earlier, we are confident that many foods in addition to the ones listed above contain very small-to-small amounts of chromium.

To summarize your best food options for increasing chromium in your meal plan: while we only show 7 WHFoods as being ranked sources of chromium, and while only 11 additional WHFoods show actual microgram amounts for chromium, we are confident that you will be getting chromium from whole, natural foods in all food groups, as well as in herbs and spices. When trying to increase your chromium intake, it's important to take a broad approach involving an overall healthy diet.

Introduction to Nutrient Rating System Chart

In order to better help you identify foods that feature a high concentration of nutrients for the calories they contain, we created a Food Rating System. This system allows us to highlight the foods that are especially rich in particular nutrients. The following chart shows the World's Healthiest Foods that are either an excellent, very good, or good source of chromium. Next to each food name, you'll find the serving size we used to calculate the food's nutrient composition, the calories contained in the serving, the amount of chromium contained in one serving size of the food, the percent Daily Value (DV%) that this amount represents, the nutrient density that we calculated for this food and nutrient, and the rating we established in our rating system. For most of our nutrient ratings, we adopted the government standards for food labeling that are found in the U.S. Food and Drug Administration's "Reference Values for Nutrition Labeling." Read more background information and details of our rating system.

World's Healthiest Foods ranked as quality sources of chromium						
Food	**Serving Size**	**Cals**	**Amount (mcg)**	**DRI/DV (%)**	**Nutrient Density**	**World's Healthiest Foods Rating**
Broccoli	1 cup	54.6	18.55	53	17.5	excellent
Barley	0.33 cup	217.1	8.16	23	1.9	good
Oats	0.25 cup	151.7	5.38	15	1.8	good
Green Beans	1 cup	43.8	2.04	6	2.4	good
Tomatoes	1 cup	32.4	1.26	4	2.0	good
Romaine Lettuce	2 cups	16.0	1.25	4	4.0	good
Black Pepper	2 tsp	14.6	0.93	3	3.3	good

World's Healthiest Foods Rating	Rule
excellent	DRI/DV>=75% OR Density>=7.6 AND DRI/DV>=10%
very good	DRI/DV>=50% OR Density>=3.4 AND DRI/DV>=5%

good	DRI/DV>=25% OR Density>=1.5 AND DRI/DV>=2.5%

Impact of Cooking, Storage and Processing

Researchers have looked at the chromium content of prepared and convenience foods, and the amount of chromium loss varies substantially with the type of food and the type of processing. There do appear to be some patterns, though.

Turning a whole grain into a refined one appears to result in a large percentage reduction in chromium content. For example, a serving of white bread contains about half the chromium of an equivalent amount of whole-wheat bread.

Cooking vegetables, at least lightly boiling or steaming them, does not appear to deplete excessive amounts of chromium. We've seen studies showing loss of approximately 5-30% chromium from vegetables cooked in this way.

Risk of Dietary Deficiency

We don't yet know if there is a true deficiency state of chromium, or if there is at what intake level it would emerge. Also, limitations in the ability to measure chromium in human tissues as well as food make it difficult to study large populations.

We do believe, however, that chromium levels vary with age, with levels going down by up to 40% in older versus younger people. This drop is probably related to dietary intake, as other research groups have concluded that chromium intake in older persons is frequently below recommended amounts.

People who eat highly refined diets, especially ones rich in simple sugars, also may be at risk of deficient chromium intake. In other words, their diet choices might leave them consuming too little chromium. One research group has also suggested that these same sugar-laden diets increase the rate of chromium loss from the body, exacerbating the deficiency risk. Given the central role of chromium in blood sugar control, this two-pronged attack on chromium status is another good reason to avoid routine intake of processed, refined foods that are also high in simple sugars.

The importance of diet quality to chromium levels is also supported by a 2011 study in which a research group taught a group of 169 overweight or prediabetic adults to eat a healthier diet—one that included more fruits, vegetables, and complex carbs than they were used to eating. In response to the healthier meal plan, blood chromium levels went up significantly from where they started.

Other Circumstances that Might Contribute to Deficiency

Once again, we do not have as much information as we would like in this area. But we do have bits and pieces of information from some specialized areas. People on prolonged intravenous nutrition often develop diabetes. There are many reasons this is true, but one potential reason is chromium deficiency. For these people, getting chromium levels back to normal can reverse the issue.

Heavy exercise can increase the rate of chromium loss in the urine. Whether this is detrimental or could exacerbate deficiency of this nutrient has not been determined.

Relationship with Other Nutrients

Vitamin C enhances the absorption of dietary chromium. For instance, women absorbed more chromium from a supplement when they were simultaneously given 100 mg of vitamin C—about the same amount you'd find in a serving of chromium-rich broccoli. While we believe this supplement study was very helpful for understanding the relationship between chromium and vitamin C, getting both nutrients from a whole, natural food is definitely the approach we recommend.

Chromium and iron can be transported on the same protein (transferrin) in the blood stream. It is plausible that too much of either of these minerals could impair metabolism of the other. But this interaction has never been demonstrated to be a problem in humans.

Risk of dietary Toxicity

Toxicity from dietary chromium has not been reported, and not very likely to occur. Studies where researchers use chromium like a drug—at doses close to 50 times more than seen with average diets—did not lead to significant risk of adverse effects.

In stark contrast to food intake and diets, there are industrial workplace settings where risk of excessive chromium exposure (in the form of hexavalent chromium, or chromium-6) can be significant. At the top of the list for higher-risk chromium exposure are welding, painting, electroplating, steel and iron manufacture, and textile dyeing. Especially in regions where the above manufacturing facilities are located (including numerous urban locations throughout the U.S.), water supplies can at greater risk for accumulation of chromium. Municipal water supplies are currently monitored by the U.S. Environmental Protection Agency (EPA) to ensure maximum chromium levels in water of 100 parts per billion (ppb) or less. If you are concerned about possible exposure to excess chromium in your drinking water, you may want to consider purchase of a home water filter certified for reduction of hexavalent chromium, or the purchase of bottled drinking water from a manufacturer who provides you with information about chromium content.

Disease Checklist

- Type 2 diabetes (prevention and treatment)
- Metabolic syndrome
- High cholesterol
- Depression

Public Health Recommendations

In 2001, the National Academy of Sciences published Dietary Reference Intakes (DRI) for chromium. These DRI recommendations came in the form of Adequate Intake (AI) levels as follows:

- 0-6 months: 0.2 mcg
- 6 months-1 year: 5.5 mcg
- 1-3 years: 11 mcg
- 4-8 years: 15 mcg
- 9-13 years, female: 21 mcg
- 9-13 years, male, 25 mcg
- 14-18 years, female: 24 mcg
- 14-18 years, male: 35 mcg
- 19-50 years, female: 25 mcg
- 19-50 years, male: 35 mcg
- 51+ years, female: 20 mcg
- 51+ years, male: 30 mcg
- Pregnant women, 14-18 years: 29 mcg
- Pregnant women, 19+ years: 30 mcg
- Lactating women, 14-18 years: 44 mcg
- Lactating women, 19+ years: 45 mcg

The NAS did not set a Tolerable Upper Intake Level (UL) for chromium.

The Daily Value (DV) for chromium is 120 micrograms (mcg) per 2000 calories. This DV target is used on food labels.

At WHFoods, we adopted the chromium DRI for 14-50 year-old males, since that level was the highest recommended intake amount for any age-gender group (except women who are breastfeeding). This DRI and WHFoods intake

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The World's Healthiest Foods

World's Healthiest Foods rich in copper		
Food	Cals	DRI/DV
Sesame Seeds	206	163%
Cashews	221	98%
Soybeans	298	78%
Mushrooms, Shiitake	41	72%
Sunflower Seeds	204	70%
Tempeh	222	68%
Garbanzo Beans	269	64%
Lentils	230	56%
Walnuts	196	53%
Lima Beans	216	49%

Basic Description

Copper is a key mineral in many different body systems. It is central to building strong tissue, maintaining blood volume, and producing energy in your cells. Yet, for all its critical importance, you don't have much copper in your body—barely more than the amount found in a single penny. And those pennies in your pocket are only 2.5% copper by weight.

In the foods we commonly eat, there are only very small amounts of copper. As much as any dietary mineral, the amount of copper you eat is directly related to the amounts of minimally processed plant foods you get every day.

Of the World's Healthiest Foods, 12 are rated as excellent sources of copper, 37 are very good, and 42 are rated as good.

Role in Health Support

Antioxidant Protection

Copper is one of the co-factors for one form of an enzyme called superoxide dismutase (SOD). SOD is one of the major antioxidant enzymes in the body. As a measure of how important SOD is, amyotrophic lateral sclerosis—also known as Lou Gehrig's disease—is thought to be the result of an underfunctioning (SOD) enzyme.

From recent studies where young volunteers were fed a copper-depleted diet, reduced SOD function was an early result. In fact, these changes were apparent within the first month of the experimental diet.

In more advanced cases of copper deficiency, including people who have undergone gastric bypass surgery, this loss of antioxidant protection over a period of years can lead to irreversible damage to the nervous system. However, this does not appear to occur without the types of unusual deficiency risks detailed below.

Bone and Tissue Integrity

Copper is required to manufacture collagen, a major structural protein in the body. When copper deficiency becomes severe, tissue integrity—particularly bones and blood vessels—can begin to break down.

Luckily, it appears at the present time that a very severe and prolonged dietary deficiency of copper is necessary to lead to overt problems. For example, premature babies with immature gastrointestinal tracts can develop bone problems related to copper deficiency.

At least one recent author has speculated that the marginal copper status of the diets of about one-quarter of adults in the U.S. is related to eventual development of osteoporosis in some members of this group. For adults with borderline copper intake from food, deficient intake of nutrients like calcium and vitamin D is still likely to put them at greater risk than borderline intake of copper. Still, this low copper intake may be increasing their risk of osteoporosis and is very likely to be the subject of future research.

Energy Support

Copper plays two key roles in energy production. First, it helps with incorporation of iron into red blood cells, preventing anemia. Second, it is involved with generation of energy from carbohydrates inside of cells.

Each of these uses of copper also requires iron, and for this reason, the symptoms of copper deficiency can mimic those of low iron intake. Lentils, and sesame seeds are just a few examples of World's Healthiest Foods rich in both iron and copper.

Cholesterol Balance

Animal studies have demonstrated that copper-deficient diets lead to increases in blood cholesterol levels. In humans, this appears to be true in some situations, but not all. This should not be a surprise, as human diets are much more varied than those of laboratory animals. Interestingly, the effect of copper deficiency appears to be through increased activity of an enzyme called *HMG-CoA reductase*—the same enzyme targeted by the most commonly prescribed cholesterol medications.

Summary of Food Sources

With the single exception of shrimp, all of the very good or excellent sources of copper among the World's Healthiest Foods are plant foods. These best copper sources are varied, however, and come from many different food groups.

Our top three sources of copper are sesame seeds, cashews, and soybeans. Any of these three foods will bring at least three-quarters of your daily copper requirement. Shiitake and crimini mushrooms are also excellent copper sources and will provide 40 to 75% of your daily need.

Many of the excellent food sources of copper are leafy greens, including turnip greens, spinach, Swiss chard, kale, and mustard greens. Asparagus and summer squash are two other excellent vegetable sources of copper.

The good and very good sources of copper include many legumes, whole grains, nuts, and seeds. For example, flax seeds, walnuts, and garbanzo beans are rated as very good sources of copper.

Combining a grain- or legume-based recipe with an excellent vegetable source of copper could very easily provide the entire daily requirement of this mineral. For example, 7-Minute Sautéed Crimini Mushrooms would meet or exceed your daily Recommended Dietary Allowance (RDA) for copper.

Introduction to Nutrient Rating System Chart

In order to better help you identify foods that feature a high concentration of nutrients for the calories they contain, we created a Food Rating System. This system allows us to highlight the foods that are especially rich in particular nutrients. The following chart shows the World's Healthiest Foods that are either an excellent, very good, or good source of copper. Next to each food name, you'll find the serving size we used to calculate the food's nutrient composition, the calories contained in the serving, the amount of copper contained in one serving size of the food, the percent Daily Value (DV%) that this amount represents, the nutrient density that we calculated for this food and nutrient, and the rating we established in our rating system. For most of our nutrient ratings, we adopted the government standards for food labeling that are found in the U.S. Food and Drug Administration's "Reference Values for Nutrition Labeling." Read more background information and details of our rating system.

World's Healthiest Foods ranked as quality sources of copper						
Food	Serving Size	Cals	Amount (mg)	DRI/DV (%)	Nutrient Density	World's Healthiest Foods Rating
Sesame Seeds	0.25 cup	206.3	1.47	163	14.3	excellent
Cashews	0.25 cup	221.2	0.88	98	8.0	excellent
Soybeans	1 cup	297.6	0.70	78	4.7	excellent
Mushrooms, Shiitake	0.50 cup	40.6	0.65	72	32.0	excellent
Beet Greens	1 cup	38.9	0.36	40	18.5	excellent
Turnip Greens	1 cup	28.8	0.36	40	25.0	excellent
Mushrooms, Crimini	1 cup	15.8	0.36	40	45.5	excellent
Spinach	1 cup	41.4	0.31	34	15.0	excellent

Asparagus	1 cup	39.6	0.30	33	15.2	excellent
Swiss Chard	1 cup	35.0	0.29	32	16.6	excellent
Kale	1 cup	36.4	0.20	22	11.0	excellent
Mustard Greens	1 cup	36.4	0.20	22	11.0	excellent
Summer Squash	1 cup	36.0	0.19	21	10.6	excellent
Sunflower Seeds	0.25 cup	204.4	0.63	70	6.2	very good
Tempeh	4 oz	222.3	0.61	68	5.5	very good
Garbanzo Beans	1 cup	269.0	0.58	64	4.3	very good
Lentils	1 cup	229.7	0.50	56	4.4	very good
Walnuts	0.25 cup	196.2	0.48	53	4.9	very good
Lima Beans	1 cup	216.2	0.44	49	4.1	very good
Pumpkin Seeds	0.25 cup	180.3	0.43	48	4.8	very good
Tofu	4 oz	164.4	0.43	48	5.2	very good
Peanuts	0.25 cup	206.9	0.42	47	4.1	very good
Kidney Beans	1 cup	224.8	0.38	42	3.4	very good
Olives	1 cup	154.6	0.34	38	4.4	very good
Sweet Potato	1 cup	180.0	0.32	36	3.6	very good
Shrimp	4 oz	134.9	0.29	32	4.3	very good
Green Peas	1 cup	115.7	0.24	27	4.1	very good
Almonds	0.25 cup	132.2	0.23	26	3.5	very good
Grapes	1 cup	104.2	0.19	21	3.6	very good
Pineapple	1 cup	82.5	0.18	20	4.4	very good
Winter Squash	1 cup	75.8	0.17	19	4.5	very good
Flaxseeds	2 TBS	74.8	0.17	19	4.5	very good
Brussels Sprouts	1 cup	56.2	0.13	14	4.6	very good
Beets	1 cup	74.8	0.13	14	3.5	very good
Raspberries	1 cup	64.0	0.11	12	3.4	very good
Tomatoes	1 cup	32.4	0.11	12	6.8	very good
Broccoli	1 cup	54.6	0.10	11	3.7	very good
Kiwifruit	1 2 inches	42.1	0.09	10	4.3	very good
Basil	0.50 cup	4.9	0.08	9	32.8	very good
Cabbage	1 cup	43.5	0.08	9	3.7	very good
Sea Vegetables	1 TBS	10.8	0.08	9	14.7	very good
Black Pepper	2 tsp	14.6	0.08	9	11.0	very good
Miso	1 TBS	34.2	0.07	8	4.1	very good
Eggplant	1 cup	34.6	0.06	7	3.5	very good
Fennel	1 cup	27.0	0.06	7	4.4	very good
Leeks	1 cup	32.2	0.06	7	3.7	very good
Parsley	0.50 cup	10.9	0.05	6	9.1	very good
Chili Peppers	2 tsp	15.2	0.05	6	6.6	very good
Romaine Lettuce	2 cups	16.0	0.05	6	6.3	very good
Garlic	6 cloves	26.8	0.05	6	3.7	very good
Navy Beans	1 cup	254.8	0.38	42	3.0	good
Pinto Beans	1 cup	244.5	0.37	41	3.0	good
Black Beans	1 cup	227.0	0.36	40	3.2	good
Quinoa	0.75 cup	222.0	0.36	40	3.2	good
Dried Peas	1 cup	231.3	0.35	39	3.0	good
Barley	0.33 cup	217.1	0.31	34	2.9	good
Millet	1 cup	207.1	0.28	31	2.7	good
Avocado	1 cup	240.0	0.28	31	2.3	good
Buckwheat	1 cup	154.6	0.25	28	3.2	good
Oats	0.25 cup	151.7	0.24	27	3.2	good

Potatoes	1 cup	160.9	0.20	22	2.5	good
Rye	0.33 cup	188.5	0.20	22	2.1	good
Brown Rice	1 cup	216.4	0.19	21	1.8	good
Sardines	3.20 oz	188.7	0.17	19	1.8	good
Pear	1 medium	101.5	0.15	17	3.0	good
Onions	1 cup	92.4	0.14	16	3.0	good
Wheat	1 cup	151.1	0.14	16	1.9	good
Raisins	0.25 cup	108.4	0.12	13	2.2	good
Papaya	1 medium	118.7	0.12	13	2.0	good
Collard Greens	1 cup	62.7	0.10	11	3.2	good
Banana	1 medium	105.0	0.09	10	1.7	good
Blueberries	1 cup	84.4	0.08	9	1.9	good
Cantaloupe	1 cup	54.4	0.07	8	2.6	good
Green Beans	1 cup	43.8	0.07	8	3.2	good
Strawberries	1 cup	46.1	0.07	8	3.0	good
Watermelon	1 cup	45.6	0.06	7	2.6	good
Grapefruit	0.50 medium	41.0	0.06	7	2.9	good
Cranberries	1 cup	46.0	0.06	7	2.6	good
Oranges	1 medium	61.6	0.06	7	1.9	good
Carrots	1 cup	50.0	0.05	6	2.0	good
Plum	1 2-1/8 inches	30.4	0.04	4	2.6	good
Cucumber	1 cup	15.6	0.04	4	5.1	good
Celery	1 cup	16.2	0.04	4	5.0	good
Cumin	2 tsp	15.8	0.04	4	5.1	good
Bok Choy	1 cup	20.4	0.03	3	2.9	good
Mustard Seeds	2 tsp	20.3	0.03	3	3.0	good
Apricot	1 whole	16.8	0.03	3	3.6	good
Figs	1 medium	37.0	0.03	3	1.6	good
Peppermint	2 TBS	5.3	0.03	3	11.3	good
Thyme	2 TBS	4.8	0.03	3	12.4	good
Turmeric	2 tsp	15.6	0.03	3	3.9	good

World's Healthiest Foods Rating	Rule
excellent	DRI/DV>=75% OR Density>=7.6 AND DRI/DV>=10%
very good	DRI/DV>=50% OR Density>=3.4 AND DRI/DV>=5%
good	DRI/DV>=25% OR Density>=1.5 AND DRI/DV>=2.5%

Impact of Cooking, Storage and Processing

Storage of foods does not significantly affect their copper content. Like other minerals, copper will stay available in your foods as long as they are properly stored for recommended periods of time.

Processing whole grains into refined ones by removing the outer layers will significantly reduce copper content. For example, refined white flour has less than half the copper content of the whole wheat kernel. This is a large price to pay nutritionally.

Along the same lines, foods that are cooked at high temperatures for extended periods can get brown on the outside. This effect is common with some cooking methods, and can substantially impair our ability to absorb the copper from foods. For more information on why we choose shorter cook times and lower temperatures to enhance the health benefits of foods, read this article.

Cooking vegetables reduces copper content in a manner that increases with both the volume of cooking water and the heating time. Lightly cooking vegetables by steaming should therefore help to minimize copper losses. For example, lightly boiling spinach only reduces the copper content by an insignificant fraction.

Risk of Dietary Deficiency

Between one-quarter to one-half of Americans fail to reach Dietary Reference Intake (DRI) recommendations for copper on a daily basis. In fact, in experimental research where scientists intentionally created copper-deficient diets, the composition of those diets was quite similar to the average U.S. diet. These copper-depleted diets were based largely around meats, refined grains, and dairy foods. As noted above, this common diet pattern was low enough in copper to cause significant detrimental effects to antioxidant enzymes within weeks.

About 5% of U.S. adults eat a diet with less copper than was used in these studies. In fact, this 5% of U.S. adults obtain less copper from their diets on a daily basis than would be found in a single serving of navy beans—a food not even close to the best source of copper in our rating system.

According to a statistical analysis published in 2011, copper deficiency risk has risen substantially over the past 75 years. This is probably most related to modern food processing methods, although copper depletion of soils may also contribute to some extent.

Other Circumstances that Might Contribute to Deficiency

Most of the non-dietary factors that contribute to copper deficiency tend to involve somewhat uncommon medical conditions. Gastric by-pass surgery stomach surgeries are two examples. Certain cancers—like pancreatic cancer—can increase risk of copper deficiency, as can celiac disease when it is poorly managed or untreated.

Relationship with Other Nutrients

Prolonged supplementation with doses of zinc that go beyond normal dietary intake ranges can interfere with copper absorption and utilization, leading to copper deficiency.

Risk of dietary Toxicity

Most U.S. adults struggle to achieve the Dietary Reference Intake (DRI) for copper intake, so the risk of dietary toxicity from copper is really only seen in a person with one of two issues.

The first issue would be a genetic condition that impairs the ability to clear copper from the body, leading to a buildup to toxic levels. The most likely reason for this is a condition called Wilson's disease, an inherited genetic mutation. Wilson's disease is both rare (as few as one case per 100,000 people) and very severe. People with this condition—and other similar genetic mutations that affect copper metabolism—are usually diagnosed by the time they reach adulthood.

A more common reason to see risk of copper toxicity is due to excessive exposure from the water supply. This is not generally caused by excessive amounts in city water supplies—these are monitored by the Environmental Protection Agency (EPA)—but by leaching from old copper pipes and fittings.

The amount of copper that is leached into water from old pipes can be significant, but it varies widely. If you have concern about the amount of copper in your tap water, you can take some simple steps to help reduce the exposure risk. First, the amount of leaching is directly related to the amount of time the water spends in the copper pipe. Use the first gallon or so of water in the morning for non-cooking tasks (for example, cleaning or watering plants). In fact, anytime you are getting drinking water from your tap, you can let the water run until you feel it get noticeably colder. Second, hot water will leach more copper than cold water, so if you want hot water for a beverage, you can use cold water and then heat it up rather than getting hot water out of your tap. Finally, you could install a water filter to remove much of the copper. Both activated charcoal and reverse osmosis filters should remove significant amounts of copper from your water. However, before taking any of these steps, make sure that toxicity risk is a greater risk for you than deficiency risk! You don't want to be lowering the amount of copper in your drinking water if you actually need more copper than you are getting from your food.

Disease Checklist

- Anemia
- High cholesterol
- Fatigue
- Low immune function
- Osteoporosis
- Wound healing
- Cardiac arrhythmia
- Arthritis

Public Health Recommendations

In 2001, the Food and Nutrition Board of the National Academy of Sciences published a set of Dietary Reference Intakes (DRIs) that established both Recommended Dietary Allowances (RDAs) and Adequate Intakes (AIs) for copper. (The recommendations for children under one year of age below are AIs, and all other recommendations are RDAs.)

- 0-6 months: 0.2 mg
- 6-12 months: 0.22 mg
- 1-3 years: 0.34 mg
- 4-8 years: 0.4 mg
- 9-13 years: 0.7 mg
- 14-18 years: 0.89 mg
- 19+ years: 0.9 mg
- Pregnant women: 1.0 mg
- Lactating women: 1.3 mg

The DRI report also established a Tolerable Upper Intake Level (UL) of 10 mg per day for adult men and women.

The Daily Value (DV) for copper is 2 mg per 2000 calories. This is the value that you will see on nutrition labels on foods.

At WHFoods, we use the DRI of 0.9 milligrams for adult men and women 19 years and older as our recommended daily intake level for copper.

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The World's Healthiest Foods

World's Healthiest Foods rich in fiber		
Food	Cals	DRI/DV
Navy Beans	255	76%
Dried Peas	231	65%
Lentils	230	63%
Pinto Beans	245	62%
Black Beans	227	60%
Lima Beans	216	53%
Garbanzo Beans	269	50%
Tempeh	222	48%
Kidney Beans	225	45%
Barley	217	42%

Basic Description

With the help of new research, our understanding of all nutrients increases over time. However, it would be hard to find a nutrient that we have learned more about in the past ten years as fiber. Everywhere you look, you will find debates about how the term "fiber" should best be defined, and about which substances should and shouldn't be classified as types of fiber. We want to provide you with full cutting-edge information about these debates, but at the same time, we want to give you simple recommendations about how to get optimal fiber benefits in your meal plan. So before explaining the new information that scientists have been discovering about fiber, our basic WHFoods Recommendations for fiber are as follows.

WHFoods Recommendations For Fiber

Food groups richest in fiber include Beans & Legumes, Vegetables, Fruits, Grains, and Nut & Seeds. Because different proportions of insoluble/soluble fiber, viscous/non-viscous fiber, and fermentable fiber can be found within each of these different food groups, we recommend that you rely on *all five groups* to provide you with optimal fiber intake. You could approach this first fiber goal on a weekly basis, or you could work these five food groups into your meal plan within a shorter period of time if you preferred.

A second goal would be meeting a minimal recommended intake level for fiber. Our recommendation at WHFoods is the same as the Food and Drug Administration's Daily Value (DV) of 25 grams. For us, this fiber level should be considered as a minimal versus optimal level. Public health organizations have not set upper limits on their fiber recommendations and we are glad that they haven't because we have seen health benefits being associated with higher levels of fiber intake, and we have not seen evidence of problems with fiber intake even three to four times the DV level in healthy persons who are routinely and consistently getting these levels of fiber from whole, natural foods. Our Healthiest Way of Eating Plan, for example, averages 52 grams of daily fiber, and we feel confident in the potential health benefits associated with that amount, even though it is double the Daily Value.

Key Features of Fiber

But before we get to current debates about fiber, let's start with some agreed-upon facts about fiber that have not changed and remain key features of this nutrient.

First, fiber has always been recognized as a plant-based nutrient. To make a simple comparison, plants have fiber in the same way that animals have muscles and bones. Fiber allows plants to maintain their shape and structure. And even though fungi (including mushrooms) are classified by scientists as belonging to their own separate category of living things, we would want to include them alongside of plants in this fiber discussion since they often contain chitooligosaccharides (CHOS) which most researchers consider a type of fiber. Although not widely popular in the U.S., there are other non-plant foods that contain CHOS and would be considered by many researchers as non-plant sources of fiber. Insects would be the largest single group here, followed by crustaceans like shrimp, crab, and lobster. While these last three crustaceans can be popular foods in the U.S., their CHOS content is not usually consumed because it is found in their outer shells which typically aren't consumed. At

WHFoods, the bottom line here is simple: for most U.S. eaters, plant foods (and fungi like mushrooms) are going to be your exclusive whole, natural food sources of fiber.

Second, fiber does not digest in the same way that most other nutrients digest. Most nutrients undergo full digestion as they get chewed, chemically transformed in our stomachs, and then combined with enzymes and digestive fluids in our small intestine. This combination of chewing plus digestive fluids plus digestive enzymes is usually sufficient to allow our bodies to digest and absorb nutrients from food. In the case of fiber, however, the above processes do not substantially alter the fiber's basic nature. Fiber passes all the way through our stomach and small intestine and then proceeds on to our large intestine, still largely recognizable as dietary fiber. Our chewing and digestive fluids and enzymes are not enough to dramatically change it. It is only in the last portion of our digestive tract—our large intestine—that fiber can undergo a major transformation; if this transformation occurs, it is not brought about by human enzymes or human digestive fluids but rather by trillions of bacteria living in our large intestine.

Current Issues in Fiber Research

Given these two basic distinctions that are fully embraced by all researchers, how has fiber become such a complicated nutrient to define? First, most scientists like to define nutrients according to their chemical structure. Their confidence in the nourishment provided to us by a vitamin like vitamin C is closely related to their ability to define vitamin C in chemical terms (i.e., a 6-carbon molecule with the chemical formula $C_6H_8O_6$). The fact that vitamin C *functions* as an antioxidant is not regarded as a defining characteristic of vitamin C, since many nutrients function as antioxidants. So scientists tend to rely on definitions involving chemical structure. But researchers also know that a simple chemical formula is not possible when it comes to fiber. From a chemistry standpoint, fiber is structurally diverse, and this diversity has made fiber more difficult than other nutrients for researchers to define and universally adopt.

Second, while some of the health benefits of fiber are unrelated to its bacterial breakdown in the large intestine, many important benefits from this nutrient depend on its transformation by bacteria. As you might imagine, with literally trillions of bacteria in our large intestine and as many as 1,000 different species, interactions between any substance and bacteria can be difficult to predict. So it can be difficult to conclusively determine if a substance should be classified as a fiber based on any function that it might serve following transformation by bacteria.

Most Common Classification Systems for Fiber

Soluble versus Insoluble Fiber. This distinction between soluble and insoluble fiber is probably the most familiar fiber classification system, and it also has the advantage of being the simplest. Fiber can be analyzed to determine how easily it dissolves in water, and fibers with a strong tendency to dissolved get classified as "soluble" while ones that don't get classified as "insoluble." In addition, as a very general rule, insoluble fibers tend to provide more benefits in the area of preventing constipation due to increased stool bulk and speeding up the rate of food passage through our digestive tract, while soluble fibers tend to provide better support for blood sugar balance, cardiovascular health, and satisfaction of appetite.

However, there are also some important disadvantages to this simple classification system. First, it is possible for fibers to have soluble and insoluble components. In this case, the distinction tends to be less helpful. Second, the vast majority of foods providing fiber not only contain both soluble and insoluble types, but they often contain both in nutritionally significant amounts. So this distinction isn't always helpful in making food choices. Third, these two categories are often insufficient to account for important health benefits. For example, within the soluble fiber group can be found both viscous and non-viscous soluble fiber. Viscous soluble fibers are gel-forming and much more closely associated with cardiovascular and blood-sugar regulating benefits than non-viscous soluble fibers. So as you can see, even though this distinction between soluble and insoluble makes sense and has value, it has seemed less helpful over time as researchers learn more and more above fiber and try to determine the best way to obtain optimal benefits from fiber-containing foods.

Dietary Reference Intake (DRI) Classification System

In 2005, the National Academy of Sciences (NAS) updated its classification system for fiber to include three basic categories: Dietary Fiber, Functional Fiber, and Total Fiber. Since the Total Fiber category was simply a combination of the first two categories, we will focus on those first two. The NAS described Dietary Fiber as fiber naturally found in plants in an intact form. By contrast, they described Functional Fiber as fiber that could naturally be found in plants, but could also be synthesized. In addition, they noted that while Functional Fiber could naturally be found in plants, it should not be placed in this category unless it has been isolated from its natural plant context through food processing. This contrast between Dietary Fiber and Functional Fiber makes sense to us if the goal is to look comprehensively at fiber with an approach that includes processed foods and dietary supplements. There are a large number of foods to which fiber has been added during processing, as well as numerous dietary supplements containing fiber.

However, a complication with this fiber classification system involves the inclusion of most fiber types in both categories. For example, some resistant starch falls into the Dietary Fiber category, and other resistant starch falls into the Functional Fiber category. The same is true for other fiber types, including oligosaccharides, pectins, gums, and lignin. So this classification can be confusing in this regard. In addition, since we only focus on whole natural foods at WHFoods, Functional Fiber (as defined by the NAS) would not be present in any of our foods, since it requires isolated fiber rather than intact, whole food fiber.

Fermentable Carbohydrate: You can find this term being used more and more often to refer to fiber. It is a term that simply refers to the ability of fiber to pass through our stomach and small intestine without being broken apart by digestive fluids and digestive enzymes, and to make it all the way to our large intestine where bacteria can "ferment" it into other substances. "Ferment" in this context simply means metabolize it into other forms. The category of fermentable carbohydrate is a great way to focus on the role of fiber in supporting balanced bacterial populations in our large intestine, but it does leave aside the other many valuable health-support roles of this nutrient.

European Food Safety Authority (EFSA) System

The EFSA system contains four basic categories of fiber based on its chemistry. From our perspective, this approach does a good job of explaining the full range of substances that can be considered as types of fiber. We would also note that all of the fiber types in the EFSA system can be found in whole, natural foods. We use this classification system for thinking about the fiber content of our foods, and have found it helpful in putting fiber research studies into context. The chart below summarizes the EFSA categories and specific types of fiber belonging to each category.

Types of Fiber

Non-Starch Polysaccharides (NSP)	Resistant Oligosaccharides	Resistant Starches	Lignin*
celluloses	fructo-oligosaccharides (FOS)	numerous dextrins	
hemicelluloses	galacto-oligosaccharides	numerous maltodextrins	
pectins	chito-oligosaccharides (CHOS)	some high-amylose starches	
hydrocolloids (gums, mucilages, beta-glucans)			

*There is only one basic molecule with a single uniform structure called "lignin," even though its three basic components (three different cinnamyl alcohols) vary in their proportion.)

Our recommendation for obtaining fiber from all five major fiber-containing food groups (Beans & Legumes, Vegetables, Fruits, Grains, and Nut & Seeds) is largely based on distribution of the ESFA fiber types throughout these five groups.

Role in Health Support

Optimal Food Passage Through the Digestive Tract

As you sit reading this article, the food that you've eaten in the past day is slowing inching its way through your digestive tract. Some days, this may seem like a sprint, but in fact, it's more of a marathon. Between the small and large intestine, food and other waste products need to travel more than 25 feet to get to the end of the journey.

This process is controlled by very carefully choreographed muscle movement, which in turn is partly triggered by the presence of food inside of our digestive tract. So, in a real sense, the amount of food inside our intestine partly controls the rate at which our muscles move.

Insoluble fiber plays a unique role in this process. Because it cannot be broken down in the small intestine, and because it has the ability to attract water to it, insoluble fiber can help control the consistency of food in our digestive tract as well as the pace at which it passes through. (To put the result in everyday terms, it can help with "regularity.") However, viscous soluble fiber also has a role to play in this process, alongside of the role played by insoluble fiber. This second type of fiber helps control the "thickness" of your food as it gets digested. It's especially important when food is in our stomach because it can help pace and regulate the passage of food out of our stomach and along to our small intestine. This moment in the digestive process is called "gastric emptying," and soluble, viscous fiber is known to help slow gastric emptying, as well as helping keep it on a steady pace. Since rate of gastric emptying is related to our blood sugar and blood insulin balance, you can see how helpful soluble viscous fiber can be in steadying the amount of food that begins its passage through the intestinal tract at any one moment in time.

Cardiovascular Benefits Including Improved Cholesterol Metabolism

Numerous cardiovascular benefits are associated with fiber intake, but we will start with one of the best-documented benefits: improved control of blood cholesterol levels. Viscous soluble fiber is able to bind with cholesterol in the intestine and prevent its uptake into the body by allowing it to be eliminated in the stool. The most viscous fibers—including the beta-glucans found in barley, oats, sea vegetables, shiitake mushrooms, and other foods, as well as the pectins found in the skins of cherries, grapes, berries, citrus fruits, and other foods—have all been shown to have blood cholesterol-lowering effects. Soluble fibers, and especially viscous soluble fibers, appear to be the best type for blood cholesterol benefits. It's important to note that in addition to the foods rich in pectins and beta-glucans listed above, there are other foods also provide substantial amounts of soluble fiber, including soluble fiber with varying degrees of viscosity. In this extended list would be included numerous other fruits and vegetables. Choosing fiber-rich fruits and vegetables is usually going to helpful in getting the cholesterol-lowering effects of soluble fiber.

Improved cholesterol levels, however, are not the only cardiovascular benefit provided by food fiber. Blood pressure reduction has also been associated with fiber intake, as has reduced overall risk of high blood pressure (hypertension). Overall risk of cardiovascular diseases—and risk of specific diseases including atherosclerosis and coronary heart disease—has been shown to decrease in association with healthy fiber intake.

Stabilization of Blood Sugar

A number of research teams have been able to demonstrate that the addition of high-fiber foods to a regular meal not already rich in fiber can improve blood sugar control if done on a consistent basis over a period of weeks (and in some cases months). In addition, studies on blood sugar problems in whole populations have shown better blood sugar control when healthy levels of fiber are consumed. In other words, fiber-rich meals can help most of us regulate our blood sugars in a healthier way. Interestingly, some studies also show that the blood sugar benefits of a fiber-rich meal can often extend throughout the day, even after a second or third meal is eaten. As an example, a fiber-rich breakfast might be able to help us steady our blood sugar levels even after eating lunch or dinner. So you can see how the meal-by-meal benefits of fiber-rich founds can overlap and help establish a steady, ongoing healthy basis for blood sugar balancing.

As mentioned earlier, part of the blood sugar-balancing benefits of fiber come from the special ability of soluble, viscous fiber to impart a slow release of food from the stomach (called gastric emptying). But blood sugar benefits from soluble fiber go even further. High-fiber meals significantly increase production of a hormone called glucogon-like peptide 1 (GLP-1), a hormone known to reduce blood sugar levels. Interestingly, one research group has also suggested that this GLP-1 response gets triggered not directly by the presence of soluble fiber, but by the products of fiber fermentation by bacteria in the large intestine. So you can see how the blood sugar benefits of fiber may involve several different factors. It is also important to note that risk of adult onset, type 2 diabetes and insulin resistance have also been found to decrease with healthy fiber intake.

Maintenance of Colon Health

There are two key ways in which fiber helps to maintain colon health. "Colon" in this context simply means all of our large intestine. Both ways involve the bacteria that live in our large intestine.

A first way that we see fiber helping to maintain colon health is by directly acting as fuel for the growth of "friendly" bacteria. Some of the bacterial species in our gut are so specialized that they can digest specific subtypes of fiber. For example, some species of *Bacteroides* break down hemicellulose as their primary fuel source, while others in the same class (bacteria that share 96% of their DNA) break down pectins as their main fuel. The reason that bacteria can digest nutrients that humans cannot comes down to their production of very specialized enzymes. In other words, there is a very intimate and mutually supportive relationship between fiber in our diet and populations of bacteria in our large intestine. These bacteria do best when our fiber intake is best, and our colon stays healthiest when these bacterial populations are thriving and in balance.

The second way that fiber helps support colon health is also related to bacterial digestion of fiber. As food fibers are digested in the large intestine by bacteria, their metabolism can provide the short-chain fatty acids (SCFAs) that cells along the large intestinal wall use as a fuel source. SCFAs—and in particular, one SCFA called butyrate—are critical for colon health because they provide cells that form the lining of the colon with the fuel they need to carry out their metabolic activities. In addition to this key support of normal intestinal function, healthy intake of fiber has also been associated with reduced risk of colon cancer.

Summary of Food Sources

An important point to remember about WHFoods and fiber is the fact that nearly three-quarters of our foods rank as good, very good, or excellent sources of this nutrient! Except for our animal foods, you will find ranked sources of fiber in all of our food groups, and in our Herbs & Spices as well. Fiber is a showcase nutrient for most any plant-based meal plan, and our WHFoods meal plans are no exception.

For the sheer total amount of fiber available from any single food group, it would be difficult not to place Beans & Legumes at the top of the list. If you measure our WHFoods strictly on the percent of the Dietary Reference Intake/Daily Value that they provide, all of our top 10 fiber-rich foods except one (barley) belong to the Beans & Legume food group. Of course, this approach does not factor in nutrient-richness and the number of calories provided by each bean serving. But even when calories and our full rating system approach is used for evaluation, Beans & Legumes still account for half of our top 10 foods.

A one-cup serving of most beans will contain approximately 10-20 grams of fiber and often provide at least half of our daily minimum recommended amount. In addition, beans contain both soluble and insoluble fiber, often at a ratio of about 1 gram of soluble to 3 grams of insoluble.

Our nutrient-richness rating system approach also places three vegetable greens—collard, turnip, and beet greens—in our top five fiber-rich foods. While you will not get 10-20 grams of fiber per serving, you will still get about 5 grams of fiber per serving and at a much lower cost in terms of calories. To give you one simple comparison, 15 grams of fiber from pinto beans will cost you about 240 calories out of your daily calorie total, and 15 grams of fiber from collard greens will cost you about 63 calories. Of course, both of these outstanding foods provide you with a wide variety of nutrients that extend far beyond fiber.

We also see whole grain foods contributing sizable amounts of dietary fiber. Grains tend to contain about five to ten grams of fiber per 1 cup serving. This food group tends to favor insoluble fiber, often with a ratio of insoluble to soluble fiber of 4:1 or sometimes greater. Oats are an exception here, with a somewhat evenly balanced ratio of the two fiber types.

Collard greens, turnip greens, and beet greens are by no means alone in providing rich amounts of fiber within the vegetables group. Other standout vegetables included in our top 25 fiber-rich foods are green peas, winter squash, broccoli, spinach, Brussels sprouts, green beans, and cabbage. Fruits also appear on our top 25 list. Within the fruit group, raspberries, pears, and cranberries are our top fiber-rich foods.

As mentioned earlier, it would be wrong to omit Nuts & Seeds as a fiber-rich group of foods. From this group we have flaxseeds in our top 25, but receiving rankings of a good source are sesame seeds and almonds.

Finally, it is important to remember that Herbs & Spices can also contain valuable amounts of fiber. Cinnamon would be a special standout here.

Let's build a sample diet that draws on a variety of food groups for outstanding fiber results. For breakfast, we'll start with granola with fresh fruit This choice will start the day with 9 grams of fiber. This combination will also provide us with valuable amounts of both soluble and insoluble fiber. For lunch, we'll have black bean chili, a recipe that contains nearly 26 grams of fiber per serving. We'll enjoy it with a pear to temper the heat from the spicy chili, and to provide another 5 grams of fiber.

For dinner, we'll make baked miso salmon. For side dishes, let's add 5-minute Brussels sprouts and warm quinoa salad. This meal will give us a variety of different fiber sources from the vegetables, grains, and herbs and spices. The 29 grams of fiber this meal will bring our fiber total to nearly 70 grams for the day!

Introduction to Nutrient Rating System Chart

In order to better help you identify foods that feature a high concentration of nutrients for the calories they contain, we created a Food Rating System. This system allows us to highlight the foods that are especially rich in particular nutrients. The following chart shows the World's Healthiest Foods that are either an excellent, very good, or good source of fiber. Next to each food name, you'll find the serving size we used to calculate the food's nutrient composition, the calories contained in the serving, the amount of fiber contained in one serving size of the food, the percent Daily Value (DV%) that this amount represents, the nutrient density that we calculated for this food and nutrient, and the rating we established in our rating system. For most of our nutrient ratings, we adopted the government standards for food labeling that are found in the U.S. Food and Drug Administration's "Reference Values for Nutrition Labeling." Read more background information and details of our rating system.

World's Healthiest Foods ranked as quality sources of fiber						
						World's

Food	Serving Size	Cals	Amount (g)	DRI/DV (%)	Nutrient Density	Healthiest Foods Rating
Navy Beans	1 cup	254.8	19.11	76	5.4	excellent
Raspberries	1 cup	64.0	7.99	32	9.0	excellent
Collard Greens	1 cup	62.7	7.60	30	8.7	excellent
Turnip Greens	1 cup	28.8	5.04	20	12.6	excellent
Beet Greens	1 cup	38.9	4.18	17	7.7	excellent
Cinnamon	2 tsp	12.8	2.76	11	15.5	excellent
Dried Peas	1 cup	231.3	16.27	65	5.1	very good
Lentils	1 cup	229.7	15.64	63	4.9	very good
Pinto Beans	1 cup	244.5	15.39	62	4.5	very good
Black Beans	1 cup	227.0	14.96	60	4.7	very good
Lima Beans	1 cup	216.2	13.16	53	4.4	very good
Tempeh	4 oz	222.3	12.00	48	3.9	very good
Kidney Beans	1 cup	224.8	11.33	45	3.6	very good
Barley	0.33 cup	217.1	10.61	42	3.5	very good
Wheat	1 cup	151.1	8.19	33	3.9	very good
Green Peas	1 cup	115.7	7.58	30	4.7	very good
Winter Squash	1 cup	75.8	5.74	23	5.4	very good
Pear	1 medium	101.5	5.52	22	3.9	very good
Broccoli	1 cup	54.6	5.15	21	6.8	very good
Cranberries	1 cup	46.0	4.60	18	7.2	very good
Spinach	1 cup	41.4	4.32	17	7.5	very good
Brussels Sprouts	1 cup	56.2	4.06	16	5.2	very good
Green Beans	1 cup	43.8	4.00	16	6.6	very good
Cabbage	1 cup	43.5	3.90	16	6.5	very good
Flaxseeds	2 TBS	74.8	3.82	15	3.7	very good
Swiss Chard	1 cup	35.0	3.67	15	7.5	very good
Asparagus	1 cup	39.6	3.60	14	6.5	very good
Carrots	1 cup	50.0	3.42	14	4.9	very good
Oranges	1 medium	61.6	3.14	13	3.7	very good
Strawberries	1 cup	46.1	2.88	12	4.5	very good
Mustard Greens	1 cup	36.4	2.80	11	5.5	very good
Fennel	1 cup	27.0	2.70	11	7.2	very good
Cauliflower	1 cup	28.5	2.68	11	6.8	very good
Kale	1 cup	36.4	2.60	10	5.1	very good
Summer Squash	1 cup	36.0	2.52	10	5.0	very good
Eggplant	1 cup	34.6	2.47	10	5.1	very good
Tomatoes	1 cup	32.4	2.16	9	4.8	very good
Kiwifruit	1 2 inches	42.1	2.07	8	3.5	very good
Romaine Lettuce	2 cups	16.0	1.97	8	8.9	very good
Chili Peppers	2 tsp	15.2	1.88	8	8.9	very good
Bell Peppers	1 cup	28.5	1.85	7	4.7	very good
Bok Choy	1 cup	20.4	1.65	7	5.8	very good
Black Pepper	2 tsp	14.6	1.47	6	7.3	very good
Cloves	2 tsp	11.5	1.42	6	8.9	very good
Celery	1 cup	16.2	1.40	6	6.2	very good
Garbanzo Beans	1 cup	269.0	12.46	50	3.3	good
Soybeans	1 cup	297.6	10.32	41	2.5	good
Avocado	1 cup	240.0	10.05	40	3.0	good
Rye	0.33 cup	188.5	8.42	34	3.2	good
Sweet Potato	1 cup	180.0	6.60	26	2.6	good

Quinoa	0.75 cup	222.0	5.18	21	1.7	good
Papaya	1 medium	118.7	4.69	19	2.8	good
Buckwheat	1 cup	154.6	4.54	18	2.1	good
Apple	1 medium	94.6	4.37	17	3.3	good
Olives	1 cup	154.6	4.30	17	2.0	good
Sesame Seeds	0.25 cup	206.3	4.25	17	1.5	good
Oats	0.25 cup	151.7	4.13	17	2.0	good
Potatoes	1 cup	160.9	3.81	15	1.7	good
Blueberries	1 cup	84.4	3.55	14	3.0	good
Beets	1 cup	74.8	3.40	14	3.3	good
Banana	1 medium	105.0	3.07	12	2.1	good
Onions	1 cup	92.4	2.94	12	2.3	good
Almonds	0.25 cup	132.2	2.81	11	1.5	good
Pineapple	1 cup	82.5	2.31	9	2.0	good
Corn	1 each	73.9	1.85	7	1.8	good
Mushrooms, Shiitake	0.50 cup	40.6	1.52	6	2.7	good
Figs	1 medium	37.0	1.45	6	2.8	good
Grapefruit	0.50 medium	41.0	1.41	6	2.5	good
Cantaloupe	1 cup	54.4	1.34	5	1.8	good
Leeks	1 cup	32.2	1.04	4	2.3	good
Parsley	0.50 cup	10.9	1.00	4	6.6	good
Miso	1 TBS	34.2	0.93	4	2.0	good
Turmeric	2 tsp	15.6	0.93	4	4.3	good
Plum	1 2-1/8 inches	30.4	0.92	4	2.2	good
Oregano	2 tsp	5.3	0.85	3	11.5	good
Apricot	1 whole	16.8	0.69	3	3.0	good
Thyme	2 TBS	4.8	0.67	3	9.9	good

World's Healthiest Foods Rating	Rule
excellent	DRI/DV>=75% OR Density>=7.6 AND DRI/DV>=10%
very good	DRI/DV>=50% OR Density>=3.4 AND DRI/DV>=5%
good	DRI/DV>=25% OR Density>=1.5 AND DRI/DV>=2.5%

Impact of Cooking, Storage and Processing

Fiber in foods does not get lost during storage. This is good news, since many important fiber-rich foods have a relatively long shelf life. Dried beans, for example, can often be safely stored for up to one year. As a reminder here, our individual food profiles provide exact storage times and steps not only for beans, but for each of our individual WHFoods.

While changes in fiber content can occur along with cooking, we do not see these changes as being problematic with whole, natural foods; relatively short cooking times; and everyday cooking methods. Beans are an interesting category of fiber-rich foods in this regard because they are typically only consumed in cooked form. We've look at fiber changes involved with overnight soaking of beans as well as stovetop boiling/simmering of beans and as a general summary, we believe you are still highly likely to get fantastic fiber-richness from cooked beans. All of the fiber data for our WHFoods beans and legumes has been calculated using their cooked form, and the same is true for all of our fiber data on grains.

Other processing steps can sometimes take a greater toll on fiber. Luckily, the canning of beans is not one of them. You'll be getting a similar level of total fiber in most commercially canned beans to the amount you will get if you cook simmer dry beans in your kitchen. However, because of the higher heats involved with canning and other processing factors, significant losses of other nutrients are definitely possible with commercial canning of beans. (Loss of molybdenum would be one example here.)

With the processing of grains, however, the impact on fiber can be much greater. The impact of grain processing on flour, for example, depends almost completely on the percent extraction used in production of the flour. While the terminology here can seem backwards from the meaning, you might expect "100% extraction" flour to mean that every single part of the original grain was included in the flour. Importantly, this 100% level includes all of the bran and all of the germ, which are the portions of the grain providing you with its fiber richness. Few breads or baked products are made with 100% extraction flour. The average extraction percentage for most U.S. breads and baked products is approximately 60%. This rate means that 60% of the original whole grain was incorporated into the flour, and 40% was discarded. Unfortunately, since most of the fiber-rich bran and fiber-rich germ from the grain was discarded, most of its fiber was discarded as well. To give you one practical example: it is not unusual to find "100% wheat bread" in the grocery store that has been made from 60% extraction flour and contains only 1 gram of fiber or less per slice.

While the cooking—and especially overcooking—of vegetables can result in significant loss of nutrients, fiber is not one of the nutrients greatly impacted by healthy cooking methods.

Risk of Dietary Deficiency

Based on the NHANES 2009-2010 survey of dietary intake, U.S. adults average only 16 grams of fiber intake per day. In fact, no age or gender group averages the Daily Value (DV) of 25 grams. For teenage girls, the average is about 12-13 grams, or the same as about 50% DV. A conclusion from this survey would be to point out that in the U.S. population as a whole, a person's risk of fiber deficiency is basically 100%. We just don't get anywhere close to enough fiber from our meal plans, even at the minimal DV level of 25 grams.

Many problematic practices contribute to this poor level of fiber intake. Included in the list would be routine consumption of heavily processed grain products, sparse consumption of fresh fruits and vegetables, and heavily reliance on animal foods. As explained in an earlier example, routine intake of whole, natural foods from the vegetables, fruits, beans and legumes, nuts and seeds, and grains food groups can easily boost fiber intake over the 25-gram level, and in the case of many of our meal plans, above the 50-gram level as well.

Other Circumstances that Might Contribute to Deficiency

Beyond the problematic, everyday food practices listed above that greatly compromised fiber intake, other diet-related practices can impact fiber intake as well. Weight loss diets that encourage very liberal intake of animal foods and severe restriction on carbohydrates can often create too little fiber intake, since animal foods do not provide fiber and since most whole, natural fiber-rich foods also provide at least moderate amounts of total carbohydrate.

While outside the scope of this nutrient profile, it is worth noting that in treatment of some health conditions requiring special feeding methods and/or special diets, fiber intake is deliberately restricted to facilitate the healing process.

Relationship with Other Nutrients

As researchers have learned more and more about the role of fiber in support of large intestine bacteria, they have also learned more about the relationship of fiber to other nutrients. As a general rule, researchers have traditionally dismissed the large intestine as a possible site for absorption of most nutrients, and they have focused instead on the small intestine when studying nutrient absorption. However, thanks to our present-day understanding of fiber as a key player in the health of our large intestine, we now know that metabolism of fiber by large intestine bacteria can result in absorption of certain nutrients from that area of the digestive tract. For example, the minerals calcium and magnesium are now included in the list of nutrients likely to be absorbed not only from the small intestine but from the large intestine as well, and in no small part due to the role played by dietary fiber. This recent research is causing new questions to be asked about the relationships between fiber and other nutrients. At least in the case of calcium and magnesium, it might be that case that increased intake of fiber in a whole, natural foods diet can increase availability of these two minerals as well.

As a general rule, research studies on fiber intake do not show problematic interactions with other nutrients. We've seen some studies showing small drops (less than 5%) in absorption of select nutrients when fiber intake was significantly increased through a combination of whole, natural foods plus processed food components (like oat bran), but high levels of fiber intake from whole, natural foods in whole population studies of diet and health generally correspond to high levels of nutrient intake overall.

Risk of dietary Toxicity

As mentioned earlier, the National Academy of Sciences (NAS) did not set any Tolerable Upper Intake Level (UL) for fiber when its fiber recommendations were updated in 2005. From studies of diets worldwide, we also know that routine dietary intake can average 75-100 grams per day when whole, natural plant foods account for the vast majority of dietary intake. The big picture here appears to be a ringing endorsement of all fiber amounts that correspond to healthy intake of whole, natural foods, even when those foods are particularly fiber-rich.

Incorporating fiber-rich foods into your personal diet, however, can take some patience and some practice. From our perspective, it is often a mistake to try and improve your fiber intake by adding processed food components like purified brans or germs. If you do take this approach, we recommend "baby steps" in the addition of these processed fibers. Cramping, gas, bloating, and other problems are fairly common when processed fibers are added too quickly to a meal plan. (For many persons, "too quickly" might mean as little as one teaspoon per day for one week, and then an increase to two teaspoons the following week.) While these problems might not be considered to involve dietary toxicity risk, we believe they are worth pointing out in this section of a fiber profile. A far better approach—and the approach we recommend—is to gradually replace one or two commonly eaten low-fiber foods (for example, processed grains) or fiber-free foods (e.g., animal foods) on multiple days of the week with a fiber-rich food, and allow your digestive tract to gradually adapt to this increased-fiber intake. For example, it might take several weeks or even several months, for a person accustomed to consuming a 15 gram-per-day meal plan to gradually increase fiber-rich, whole, natural foods intake to a level two or three times that amount.

Finally, we would repeat our previous mention that certain health problems can call for restricted fiber intake. In these situations, high intake of fiber could be thought of as posing a risk of dietary toxicity risk. But in the vast majority of situations, high intake of dietary fiber not only poses no toxicity risk, but has been shown to make possible health benefits that may not be available at minimal intake levels.

Disease Checklist

- Constipation
- Irritable bowel syndrome
- Colon cancer
- Breast cancer
- Peptic ulcer
- Heart disease
- Type 2 diabetes
- Inflammatory bowel disease
- Hypertension
- Coronary heart disease
- Insulin resistance
- Metabolic syndrome
- Stroke

Public Health Recommendations

In 2005, the National Academy of Sciences (NAS) updated its recommendations for fiber intake. These recommendations appear below.

- 0—1 year: Not determined
- 1—3 years: 19 grams
- 4—8 years: 25 grams
- 9—13 years, female: 26 grams
- 9—13 years, male: 31 grams
- 14—18 years, female: 26 grams
- 14—18 years, male: 38 grams
- 19—50 years, female: 25 grams
- 19—50 years, male: 38 grams
- 51+ years, female: 21 grams
- 51+ years, male: 30 years
- Pregnant women: 28 grams
- Lactating women: 29 grams

The NAS chose not to establish a Tolerable Upper Intake Limit (UL) for fiber intake.

The Daily Value (DV) for fiber is 25 grams per day. The DV is the standard that you will see on food labels. The DV is also the standard that we adopted as our WHFoods recommended minimal daily intake level. However, our meal plans typically provide substantially higher amounts of fiber than the DV. As one example, our Healthiest Way of Eating Plan averages 52 grams of daily dietary fiber.

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The World's Healthiest Foods

Flavonoids are one of the largest nutrient families known to scientists, and include over 6,000 already-identified family members. Some of the best-known flavonoids include quercetin, kaempferol, catechins, and anthocyanidins. This nutrient group is most famous for its antioxidant and anti-inflammatory health benefits, as well as its contribution of vibrant color to the foods we eat. As an especially delicate group of nutrients with respect to cooking heats, flavonoids are often front and center in development of our cooking methods at WHFoods, where we always look for cooking methods best able to preserve nutrients. Due to unusually incomplete research information, we do not list values for specific flavonoids in our in-depth nutritional profiles for our foods, nor do we rank our foods based on their flavonoid content. However, in the Summary of Food Sources section of this article, you can find best food sources for five basic categories of flavonoids (including flavonols, flavan-3-ols, flavones, flavonones, and anthocyanidins).

Basic Description

The unique nutrient richness of every whole, natural food can be showcased in a variety of ways. But there is no better way to highlight the unique nutrient richness of foods than to focus on their flavonoid content! Flavonoids are a quite remarkable group of phytonutrients that fall into the chemical category of polyphenols. They're perhaps most famous for their rich diversity of color-providing pigments (including the deep blues of blueberries and rich reds of raspberries). The name of these phytonutrients actually derives from their color-related chemistry, with the Latin word *flavus* meaning "yellow." As a group, however, flavonoids are highly bioactive and play a wide variety of different roles in the health of plants, animals, and human health.

The flavonoid nutrient family is one of the largest nutrient families known to scientists. Over 6,000 unique flavonoids have been identified in research studies, and many of these flavonoids are found in plants that are routinely enjoyed in delicious cuisines throughout the world. In terms of nutrient richness, we get far more flavonoids from plant foods than from animal foods, and in particular, vegetables and fruits can be especially nutrient-rich in this type of phytonutrient.

Some of the most widely-studied flavonoids are nutrients you may already have heard about not in particular connection with any specific food—for example, the flavonoid quercetin. Other flavonoids you may have heard about due to their association with a particular food—for example, the catechins in green tea. Sometimes a flavonoid is actually easy to link up with its most nutrient-rich food sources— for example, the tangeretin found in tangerines (as well as other citrus fruits).

Flavonoids are best known for their antioxidant and anti-inflammatory health benefits as well as the support of the cardiovascular and nervous systems. Because they also help support detoxification of potentially tissue-damaging molecules, their intake has often, although not always, been associated with decreased risk of certain types of cancers, including lung and breast cancer. However, it is important to note that the amount of flavonoids required to provide the above health benefits is not certain, and there are some conflicting research findings in this regard. You will find more details about the health benefits of flavonoids in the Role in Health Support section of this profile.

We will also be providing you with more detailed information about flavonoids and specific foods in our Summary of Food Sources section.

Role in Health Support

Antioxidant Benefits

Because many flavonoids—and especially those belonging to two flavonoid subgroups called flavonols and flavan-3-ols—can be effective in reducing free radical damage to cells and other components in body tissue, they provide antioxidant benefits. It is not clear, however, if we should be thinking about flavonoids as falling into the same category as more widely known antioxidant nutrients like vitamin C or vitamin E.

One reason for this is because their concentration in the bloodstream is so much lower. Another reason lies in the fact that many of the antioxidant functions of the flavonoids are not performed by the flavonoids themselves, but by forms of the flavonoids that have been altered by our metabolism. Even though we do not know all the details about the way flavonoids function as antioxidants, however, studies have documented better protection of certain cell types—for example, red blood cells—following consumption of flavonoid-rich foods. Blueberries, for example, have been repeatedly studied in this context for their flavonoid-related antioxidant benefits.

In this antioxidant context, it is also worth pointing out the potentially unique relationship between flavonoids and vitamin C. Recent studies have shown the ability of flavonoids to alter transport of vitamin C, as well as to alter function of an enzyme called *ascorbate oxidase*, which converts vitamin C into a non-vitamin form (monodehydroascorbate). While we do not yet know the full meaning of these relationships, it is clear that the transport and cycling of vitamin C is flavonoid related. This association makes sense to us, since so many foods high in vitamin C (such as our top five WHFoods for vitamin C are papaya, bell peppers, broccoli, Brussels sprouts, and strawberries) are also high in flavonoids.

Anti-Inflammatory Benefits

Much of the research on flavonoids as anti-inflammatories has involved their ability to block the production of messaging molecules that promote inflammation. In metabolic terms, this activity of flavonoids involves the inhibition of *cyclo-oxygenase* (COX) and *lipoxygenase* (LOX) enzymes. Not only have specific flavonoids (for example, quercetin) been shown to provide these benefits but so also have flavonoid-containing extracts from a variety of foods, spices, and herbs. In addition to the metabolic activities described above, food flavonoids have also been shown to suppress inflammatory signaling in another metabolic pathway called the nuclear factor kappa-B (NF-kB) pathway.

Cardiovascular System Benefits

Not surprisingly, since many problems in the cardiovascular system involve problems with oxidative stress and inflammation, the antioxidant and anti-inflammatory benefits from food flavonoids provide direct support for this body system. In the bloodstream, flavonoids have been shown to help protect LDL cholesterol molecules from oxygen-related damage. This LDL protection, in turn, helps to lower risk of atherosclerosis. Flavonoids including rutin and hesperidin have also been shown to increase the strength and integrity of the blood vessel walls, lowering risk of blood vessel problems. In one study, adding a spice mix to a meal of beef—a mix that contained such flavonoid-rich herbs as oregano, rosemary, garlic, ginger, and black pepper—led to a significant improvement in vascular function over the next several hours. Yet herbs and spices are by no means the only foods studied in this regard; similar effects have been demonstrated for soy foods, chocolate, pomegranate juice, and grape juice.

Finally, numerous flavonoids—including quercetin and rutin—have been shown to help prevent excessive clumping together of platelet cells that could otherwise lead to unwanted clogging of the blood vessels. This property of flavonoids is called an "anti-aggregatory" property, and it's yet another way in which these phytonutrients help support the cardiovascular system.

In 2014, a research group looked at cardiovascular benefits related to the flavonoid content of fruits and vegetables. These researchers were able to determine that six total fruit and vegetable servings did a better job at protecting cardiovascular health than four total servings. They also decided upon six total servings of fruits-plus-vegetables as their minimal recommendation for heart health. Many of our daily sample menus at WHFoods go beyond this recommendation and include between 6-10 total servings from these two food groups.

Support of the Nervous System

Protection of nerve cells from oxygen-based damage, and help during the slow and demanding process of nerve regeneration (outside of the brain and spinal cord), are both demonstrated benefits of flavonoid intake for the nervous system. There is some preliminary evidence that the onset of certain chronic neurodegenerative diseases—including age-related dementia and Alzheimer's disease—may be delayed when long-term intake of flavonoids has been strong.

Because flavonoids may help to improve blood flow in the brain, there is also preliminary evidence to suggest the possibility of better brain functioning in some areas, including areas involving cognitive function.

Other Health Benefits

In terms of their anti-cancer potential, research on flavonoids has been somewhat mixed. Due to their well-documented antioxidant and anti-inflammatory properties, flavonoids would be expected to lower risk of certain cancers since chronic oxidative stress and chronic unwanted inflammation can place cells at greater risk of becoming cancerous. Furthermore, because flavonoids are known to modify the body's detoxification pathways, it might be expected that flavonoids would help lower exposure to unwanted toxins that could pose increased cancer risk. In studies on animals and on isolated cell types, the above expectations seem to be fully met, with flavonoid intake improving detoxification, oxidative stress, unwanted inflammation, and initiation of cells into pre-cancerous states. However, in larger scale studies on humans and risk of human cancers, greater intake of flavonoids has not been consistently associated with decreased risk of cancer. To date, the strongest evidence appears to involve breast cancer and lung cancer where decreased risk is a more consistent finding.

We suspect that part of the mixed findings in this flavonoids-and-cancer area might involve the complex nature of flavonoids as a group. For example, it may be the case that certain subgroups of flavonoids are particularly helpful for lowering risk of certain types of cancer. It might also be the case that studies have had trouble accurately quantifying flavonoid intake. There are thousands and thousands of food flavonoids, and yet some studies have only focused on very select examples or limited types of foods.

Improved detoxification is a very likely benefit that we get from strong flavonoid intake; yet, like with the area of cancer risk, research here has been somewhat mixed. When the cells in our body detoxify unwanted contaminants, there are two key steps involved in the process. In a first step (called Phase 1), potentially damaging molecules are made more reactive so that they can be passed on to Phase 2. In this second, Phase 2 step, the activated molecules get neutralized by being combined with a second neutralizing molecule. Flavonoids can impact both steps in detoxification (Phase 1 and Phase 2). With Phase 2, these influences seems fairly consistent because they tend to promote the combining/neutralizing goal of Phase 2. However, with respect to Phase 1, the role of flavonoids is more complicated since they can switch Phase 1 either on or off. In other words, they can both facilitate and block this first step in detoxification. This complicated relationship between flavonoids and detoxification has resulted in some mixed research findings, although overall, most researchers have concluded that strong flavonoid intake modified detoxification in a helpful way and decreases our risk of problems from unwanted toxins.

A final potential health benefit we want to mention is better regulation of cell cycles. Most cells in our body go through stages of activity where they rest, divide, or go into a self-dismantling and self-recycling process called apoptosis. In the health of all our body systems, it is important for these cell cycle stages to stay in balance. Ample intake of food flavonoids appears to promote these cell cycle balances, most likely through regulation of signaling that takes place between cells and their surroundings.

Summary of Food Sources

Flavonoids are produced by plants, and plant foods are by far our greatest source of these health-supporting phytonutrients. Among all plant food groups, by far it's been fruits and vegetables that have been best studied and most analyzed for their flavonoid content. There is also flavonoid data on nuts and seeds, grains, beans and legumes, and select other foods and beverages (for example, green and black tea).

It's important to remember that flavonoids are a very large (more than 6,000 have been so far identified) and very diverse group of phytonutrients. The U.S. Department of Agriculture's (USDA) Flavonoid Database actually breaks down its flavonoid analyses into five of the basic flavonoid chemical subgroups, and it analyzes the best food choices in each of these subgroups. We like this approach to understanding the flavonoid content of food, because it emphasizes the need to consume a wide variety of flavonoids that includes all of the different types. In keeping with this approach, the charts below will show you our top WHFoods in each of the flavonoid subcategories. The five subcategories shown in the charts below are: (1) flavonols (which include quercetin, kaempferol, myricetin, and isorhamnetin); (2) flavan-3-ols (which include catechins, epicatechins, gallocatechins, and theaflavins); (3) flavones (which include apigenin and luteolin); (4) flavonones (which include hesperetin, naringenin, and eriodictyol); and (5) anthocyanidins (which include cyanidin, delphinidin, malvidin, pelargonidin, peonidin, and petunidin).

WHFoods Best Sources of Flavonoids

flavonols	flavan-3-ols*	flavones	flavonones	anthocyanidins
onions	apples	parsley	oranges	blueberries
apples	bananas	bell peppers	grapefruit	bananas
romaine lettuce	blueberries	celery	lemons	strawberries
tomatoes	peaches	apples	tomatoes	cherries
garbanzo beans	pears	oranges		pears
almonds	strawberries	watermelon		cabbage
turnip greens		chili peppers		cranberries
sweet potatoes		cantaloupe		plums
quinoa		lettuce		raspberries
				garbanzo beans

*It's important to note that in the U.S. the largest single source of flavonoids is black and green tea, and that over half of all flavonoid intake comes from the flavan-3-ol subgroup that is so concentrated in tea; this subgroup includes catechins, epicatechins, gallocatechins, and theaflavins.

As you can see, it takes a variety of foods from a variety of different food groups to give you a good cross-section of flavonoid subcategories. The USDA estimates that in the U.S., daily total flavonoid consumption by the average adult is approximately 250-275 milligrams, with about half of total consumption coming in the form of flavan-3-ols from black and green tea.

The colorful reds, blues, and purples in berries are provided by their anthocyanidins, and that is why you find so many of these fruits listed in the anthocyanidin column.

As a group of phytonutrients, flavonoids emphasize—in a way that is not as well emphasized by perhaps any other nutrient—how valuable fruits and vegetables are to our nourishment and everyday health.

Food Source Analysis not Available for this Nutrient

Impact of Cooking, Storage and Processing

You will lose some flavonoids from plant foods during prolonged storage. For example, onions stored at room temperature will lose about one quarter to one third of their original flavonoid content over six months, with most of the loss occurring in the first two weeks.

As water-soluble nutrients, flavonoids can be lost through water contact, and in some cases, up to 80% of specific flavonoids can be lost into cooking water during the boiling of foods. Because many flavonoids provide visible colors in a food, loss of flavonoids during boiling can often be seen in a dulling of the food's colors. Color changes of this kind are one of the indicators we use for overcooking; if you boil or steam a food long enough to see its vibrant colors start to dull or disappear, you can be sure that you are losing too many valuable nutrients from the food, including its health-supportive flavonoids.

Flavonoids are susceptible to damage by heat, and as mentioned earlier, they are also susceptible to damage over prolonged periods of time. This issue of time brings us to the benefits of fresh fruits and vegetables, which are likely to be more flavonoid-rich the fresher they are at the time of purchase. The issue of heat is one of the reasons we caution against frying or lengthy cooking even in medium heats. (Our Healthy Sauté method, for example, typically calls for cooking times of 5-8 minutes or less.)

Finally, we would note that flavonoids are often concentrated in the skins and outer portions of fruits and vegetables, and that these portions of the foods are excellent to consume. Due to risk of contamination on these outermost surfaces, you always want to wash the foods and gently scrub them with a vegetable brush. Of course, you can also reduce risk of contamination by purchasing certified organic foods. When you are storing flavonoid-rich foods, it is best not to damage their skins prior to storage, for example, by pre-cutting, pre-slicing, or pre-peeling and then placing in the refrigerator. They are best kept in whole, natural form until you are ready to consume them or prepare them for inclusion in a recipe.

Risk of Dietary Deficiency

As mentioned earlier, average consumption of flavonoids in the U.S. is far less than 1 gram per day (at about 250-275 milligrams), with black and green tea serving as the number one source of these phytonutrients. While we would classify this level of intake to be inadequate from a health standpoint, we don't have a good standard to use in determining optimal flavonoid amounts. There is no Dietary Reference Intake (DRI) for flavonoids and no Daily Value (DV); in addition, nutrient databases do no provide anywhere close to comprehensive information about the overall flavonoid content of foods. All of these limitations make statements about dietary deficiency somewhat tentative. However, from a common sense standpoint, let's say that a person consumed six vegetable and four fruit servings in a day, for a total of 10 vegetable-plus-fruit servings. Furthermore, let's say that all of these servings came from whole, natural foods. In this situation, a person's total flavonoid intake would be likely to fall somewhere near 1 gram (1,000 milligrams) or more. It is within this context that we consider average flavonoid intake in the U.S. to be inadequate. In addition, since a disproportional amount of U.S. flavonoids come from a single flavonoid subgroup (flavan-3-ols provided from black and green tea), there is likely to be flavonoid deficiency from the other subgroups given the pattern of flavonoid consumption in the U.S.

Risk of dietary deficiency for flavonoids is basically synonymous with low dietary intake of whole, natural foods, and in particular, low intake of vegetables and fruits. By far your best way to ensure ample flavonoid intake is to maximize your intake of whole natural foods, including fresh, brightly colored vegetables and fruits whose flavonoid pigments provide them with their vibrant colors. This approach sounds simple, and it is a great method for increasing your flavonoid intake.

Other Circumstances that Might Contribute to Deficiency

Most documented risks for flavonoid deficiency have already been discussed since they involve poor dietary intake. Overconsumption of processed foods, overcooking of foods, and underconsumption of fresh vegetables and fruits are the primary circumstances related to deficiency. Problems with the chewing of fresh foods can increase a person's flavonoid deficiency risk, especially if these foods are avoided in a meal plan due to chewing problems. Lack of appetite can also put a person at risk of deficiency, simply due to overall low intake. In studies of the overall U.S. population, inadequate intake of nutrients—including flavonoids—can be associated with poverty and general lack of access to fresh foods.

Relationship with Other Nutrients

As described earlier, a unique relationship exists between flavonoids and vitamin C. Flavonoids affect the transport of vitamin C around the body, and they also help regulate the function of an enzyme called *ascorbate oxidase*, which converts vitamin C into a non-vitamin form (monodehydroascorbate). While we do not yet know the full meaning of these relationships, it is clear that these nutrients have a special and unique relationship. The uniqueness of their relationship makes sense to us since so many foods are high in both flavonoids and vitamin C. Our top five WHFoods for vitamin C—namely papaya, bell peppers, broccoli, Brussels sprouts, and strawberries—are great examples since each of these foods is rich in flavonoids as well.

Risk of dietary Toxicity

We are not aware of any evidence that dietary flavonoids can be directly toxic, even in meal plans that contain an abundance of fresh vegetables and fruits as well as an abundance of nuts, seeds, beans, legumes, and whole grains. When consumption of the foods above is very high, the total fiber content of the diet usually goes up dramatically. (In comparison to average fiber intake in the U.S., which averages about 16 grams per day, fiber intake in countries with high consumption of the foods above often exceeds 100 grams. (Even our Healthiest Way of Eating Plan averages over 50 grams of daily fiber.) So we would expect high flavonoid intake from whole natural foods to accompany diets high in dietary fiber, and we just do not see toxicity risks being associated with this type of dietary intake.

In addition, since flavonoids are water-soluble, we would expect them to follow a pattern associated with other water-soluble nutrients. That pattern involves lower risk of toxicity than is associated with fat-soluble nutrients, and in many cases, a decision by the National Academy of Sciences (NAS) not to establish a Tolerable Upper Intake Level (UL) for water-soluble vitamins like vitamin B1 or vitamin B2 when obtained from food. We suspect that a similar decision might end up holding true for flavonoids as well, although it's important to remember that the NAS has yet to even establish flavonoids as a required human nutrient or to set Dietary Reference Intake (DRI) amounts for flavonoids as a group or for any specific flavonoid.

Disease Checklist

- Easy bruising
- Skin damage from sun
- Hay fever
- Prostatitis
- Osteoarthritis
- Rheumatoid arthritis
- Hot flashes
- Venous insufficiency
- Cardiovascular disease (prevention)
- Low immune function
- COPD (Chronic Obstructive Pulmonary Disease)

Public Health Recommendations

As described earlier, there are no specific public health recommendations for flavonoid intake. There are currently no Dietary Reference Intakes (DRIs) from the National Academy of Sciences and there is no Daily Value (DV) from the U.S. Food and Drug Administration. However, as described earlier in our Risk of Dietary Toxicity section, our recommendation for optimal flavonoid intake is to focus on a whole, natural, fresh foods diet that provides ample servings of vegetables and fruits. In many of our sample daily meal plans, the total vegetable-plus-fruit servings add up to 5-8 servings or more. When coupled with other flavonoid-rich foods—including nuts, seeds, beans, legumes, and whole grains—your flavonoid intake is likely to far surpass

the current U.S. average level of approximately 250-275 milligrams, and may in fact get closer to a level of approaching 1 gram (1,000 milligrams).

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The World's Healthiest Foods

World's Healthiest Foods rich in folate		
Food	Cals	DRI/DV
Lentils	230	90%
Pinto Beans	245	74%
Garbanzo Beans	269	71%
Asparagus	40	67%
Spinach	41	66%
Navy Beans	255	64%
Black Beans	227	64%
Kidney Beans	225	58%
Turnip Greens	29	42%
Broccoli	55	42%

Basic Description

Arguably, no conventional nutrient has undergone as much of a research renaissance in recent years as folate. Many people are familiar with the name of this B complex vitamin, and it has long been recognized as a key nutrient in human health. Low intakes of folate can have devastating effects, ranging from birth defects to blood diseases and possibly even cancers.

Much more recent in our understanding of this critical B vitamin is its many different forms in food, and its influence far beyond birth defects, blood diseases, and cancers. In our Role in Health Support section, we will be giving you many more details on exciting new folate research.

If the word folate sounds like foliage to you, this is not an accident. The words share a common root (the Latin word folium, meaning "leaf"), which helps remind us that green plant foods can be among the richest sources of folate. However, as the chart and table in this article show, there are outstanding sources of folate in other food groups as well (especially legumes). .

Because of the promising role of folate in disease risk reduction, U.S. public health organizations have taken many steps to help increase intake of folate in the U.S. population. These public health programs have helped decrease the occurrence of neural tube defects associated with folate deficiency by as much as 30% over time. (Although enrichment of processed wheat flour with vitamins B1, B2, and B3 was practiced in the U.S. as early as the 1940's, it wasn't until 1998 that the U.S. Food and Drug Administration established guidelines for enrichment of processed wheat flour with folate.)

The adult Dietary Reference Intake (DRI) level for folate—and our WHFoods recommended daily intake level—is 400 micrograms DFE, where "DFE" stands for "Dietary Folate Equivalents." In the 2009-2010 National Health and Nutrition Examination Survey (NHANES), both male and female adults in the U.S. averaged well over this amount, with approximately 475 mcg DFE for adult women and 625 mcg DFE for adult men. However, a significant amount of this folate came in the form of fortified foods, enriched foods, or folate supplements rather than whole, natural foods. From a health standpoint, our WHFoods recommendations always focus on whole, natural foods, and if you regularly enjoy our recipes, you will be likely to do just as well as the average U.S. adult in your food-based intake of folate, without resorting to fortification or enrichment. Dozens of our recipes contain more than half of the recommended daily intake level for this B vitamin.

Our profiled foods include 10 excellent sources of folate, 17 very good sources, and 24 good sources. Included in these ranked sources of folate are foods from various food groups, including vegetables, fruits, and legumes. Given this wide variety of choices, we are confident about your ability to develop a whole foods meal plan that will provide you with plenty of folate.

Role in Health Support

As mentioned earlier, the past decade of folate research has taught us much more about the nature of this vitamin and its critical role in support of our health. However, we would also point out that, in general, folate has been a complicated vitamin for researchers to understand, and research on folate has produced some confusion when scientific findings need to get translated into practical steps that we can take in the grocery store and in the kitchen. Our goal in these next paragraphs is provide you with a framework for simplifying key aspects of recent research on this B vitamin.

Let's start off with the name of the vitamin itself. "Folate" is a very general name for a complicated family of nutrients found in both plant and animal foods. (At WHFoods, we use this very general term as our name for this B vitamin, and when we use it, we are not trying to specify any particular form of the vitamin. We just want to refer to this B vitamin in a consistent way.) To give you an idea of many different folate forms in food, consider the following list: methylfolates, dihydrofolates, monoglutamyl folates, and polyglutamyl folates. All of these vitamin forms can be found in varying amounts in whole, natural foods. By contrast, fortified and enriched foods are typically boosted in content with a single form of this vitamin, namely, folic acid. While you can find not only folic acid but many different forms of folate available in the form of dietary supplements, this vitamin gets added to food almost exclusively in the form of folic acid.

This complicated situation involving fortified foods led the National Academy of Sciences (NAS) to establish a new category for measuring dietary folate, called Dietary Folate Equivalents, or DFEs. If you consume 1 microgram of folate from a whole natural food, the NAS considers you to have consumed 1 microgram DFE. However, if you consume 1 microgram of folate from a food that has been fortified with folic acid, the NAS considers you to have consumed 1.6 micrograms DFE. Finally, if you take a folic acid supplement on an empty stomach in which no foods are simultaneously being consumed, the NAS considers you to have consumed 2 micrograms DFE. These differences in DFE calculation are based on studies measuring blood folate levels following intake of folate in various forms. The higher DFEs reflect higher blood levels associated with intake of supplemental folic acid versus natural food folate.

However, in order to more fully understand the health benefits of this vitamin, it would be a mistake to stop our discussion with consideration of supplemental folic acid, food folate, and DFEs. During the time that has passed since the NAS establishment of folate DFEs in 1998, there have been numerous advances in research on this vitamin. In comparison to the original DFE research, which showed about 50-60% bioavailability of food folate versus 85% bioavailability of supplemental folic acid, we now know that "bioavailable" can have many meanings and blood levels of folate are not always the best way to measure bioavailability. For example, we now know that polyglutamated folate found in vegetables and citrus fruits can be absorbed in the 60-98% range. We also know that a methylated form of folate (5-methyl-tetrahydrofolate) is the major form of folate in most plant cells, and that methylfolate appears to be the only form of this vitamin that crosses over the blood brain barrier and into the brain. This research has greatly increased interest in whole foods and the extent to which they naturally contain methylfolates.

Taken as a whole, these more recent research studies suggest that folate DFEs do not tell the whole story of this vitamin with respect to health benefits, and that whole, natural foods providing folate in a variety of forms are likely to be your best bet for obtaining health benefits related to this B vitamin. With this general guideline in mind, we would like to highlight specific areas in which folate health benefits have been most consistently documented in research studies.

Brain and Nervous System Health

Folate has long been known to help support production of nervous system function, and in particular, production of messaging molecules that are used by nerves to send signals throughout out body. More recently, however, research has broadened our understanding in this area of folate benefits.

In what has come to be named the BH_4 Cycle (where is an abbreviation for tetrahydrobiopterin), researchers have verified a close connection between production of multiple neurotransmitters (with special emphasis on serotonin and dopamine) and availability of folate. In fact, part of the molecule for which this BH_4 Cycle is named (dihydrobiopterin, or BH_2) can itself be readily converted into a form of folate (dihydrofolate). In addition, researchers now know that BH_4 cross over the blood brain barrier using the same transport mechanism as folate.

Interest in these nervous system messaging molecules and folate has been fascinating and widespread. Since much of the dopamine produced in our nerve cells begins with conversion of one amino acid (phenylalanine) into another amino acid (tyrosine), folate availability has been shown to be closely connected with this neurotransmitter pathway since BH_4 is required for conversion of phenylalanine into tyrosine. Yet broader still are possible connections between two additional neurotransmitters—glutamic acid and GABA—and folate metabolism.

Glutamine is the preeminent amino acid in our central nervous system, and it is the starting point for production of both glutamic acid and GABA. While glutamic acid is widely known as an "excitatory" neurotransmitter that can stimulate and speed up nerve cell activity, it actually plays a much wider role in nervous system health that includes proper brain development, differentiation of nerve cells, and survival of nerve cells. By contrast, GABA (gamma-aminobutyric acid) is widely regarded as a primary inhibitory neurotransmitter that can decrease nerve activity in certain areas and help initiate nervous system balance needed to pave the way for activities like sleep. Researchers do not yet know exactly how folate metabolism is related to metabolism of either glutamic aid or GABA. But what researchers do know is that folate is a B

vitamin that contains a "tail" comprised of glutamic acid molecules. In fact, this glutamic acid vitamin "tail" controls absorption of folate from our intestines up into our body.

Overall Cardiovascular Support

During the past 10 years, research on the role of folate in nervous system support has greatly overlapped with folate research as it relates to support of the cardiovascular system. In fact, it might be hard to find an area of metabolic research that has generated more excitement that this overlapping area of folated-related events critical for health of our cardiovascular and nervous systems.

The overlap begins with the ability of adequate dietary folate to help keep blood levels of homocysteine in check. Homocysteine (Hcy) is a well-documented marker for cardiovascular disease that when excessive, represents a clearly increased risk for a variety of cardiovascular problems. (Hyperhomocysteinemia is the name of the condition for high Hcy in the blood.) Optimal levels of blood folate in one particular form (5-methyltetrahydrofolate, or 5-MTHF) can directly help lower Hcy levels. By helping to keep Hcy levels in check, healthy intake of folate can help lower risk of cardiovascular disease.

The benefits of folate for lowered cardiovascular risk do not stop with Hcy, however. Balanced levels of nitric oxide (NO) in the blood are equally well-established as being important for cardiovascular health. NO helps to regulate many cardiovascular functions, and appropriate levels of NO are considered protective again high blood pressure, excessive clumping of platelet cells, and other key aspects of blood flow.

Several different forms of an enzyme called nitric oxide synthase (NOS) are responsible for helping keep NO at appropriate levels in our blood. However, NOS enzymes cannot actually generate NO unless certain molecules are present to help the NOS enzymes function properly. One such molecule is BH_4 (tetrahydrobiopterin). Without enough BH_4 around, the NOS enzymes not only fail to produce enough NO, but they can actually worsen our cardiovascular health by producing too much of an oxygen free radical called superoxide. How is it that our bodies keep enough BH_4 around? Our bodies accomplish this task with the help of an enzyme called dihydrofolate reductase (DHFR). Of course, you can easily recognize the word "folate" in the name of this enzyme, because it is the same enzyme that converts folate into its most central bioactive form in the body, called tetrahydrofolate, or THF. In other words, the same enzyme that makes sure we have enough BH_4 around to keep up our nitric oxide levels also makes sure that we have the most centrally active form of folate. So you can see how our folate metabolism and our cardiovascular health are so closely connected on a metabolic level.

The key role of folate in our cardiovascular health does not stop here, however. It turns out that the overall cycle used by our body to regenerate active forms of folate—called the folate cycle—is directly tied to a central cycle in cardiovascular health called the methylation cycle. The methylation cycle is our primary way of understanding blood homocysteine levels, since this cycle continually interconverts the amino acid methionine (MET) and its fellow amino acid, homocysteine (Hcy). When our folate cycle breaks down, our methylation cycle breaks down. However, the way in which our methylation cycle breaks down is important because a breakdown in our folate cycle means a breakdown in our conversion of Hcy back into MET. In other words, a breakdown in our folate cycle means excessive accumulation of Hcy and increased risk of heart disease.

As complicated as these metabolic pathways might seem, the bottom line here is straightforward: folate is a central nutrient for cardiovascular health, and its role in cardio support is wide-ranging.

Specific Support of Red Blood Cell Production

It would be wrong to leave the topic of folate and cardiovascular health without making a special note about red blood cell production. Folate is one of many nutrients necessary for the production of red blood cells. These cells carry oxygen from the lungs to other parts of the body. Along with iron, copper, vitamin B12, and vitamin B6, a deficiency of folate can impair blood cell production.

Still, the deficiency of folate must be fairly severe to impair the production of red blood cells. Although this can occur, it is rare in the United States, where adults average more than the recommended daily intake level.

Reproductive Health

When women deficient in dietary folate become pregnant, the developing fetus is at increased risk for neural tube defects, a developmental condition that adversely affects nervous system development in the fetus. These neural tube defects are potentially devastating and can often cause loss of pregnancy.

Adverse effects on nervous system development in the fetus can occur very early in pregnancy, even before a woman is aware that she is pregnant. Because this very early occurrence of problems can be "invisible," it is important for women to consume enough of this nutrient *before* they become pregnant. From a practical standpoint, this scenario means special attention to folate intake by any woman who is considering pregnancy. As noted earlier, current evidence supports a conclusion that better folate intake by women prior to pregnancy can directly reduce risk of neural tube defects in a significant way.

Other Potential Health Benefits

Some studies show lower risk of breast cancer in women with higher dietary intakes of folate, as well as decreased cancer risk at other sites in both men and women. However, the overall research on folate and cancer risk is both controversial and on the surface, sometimes contradictory, since some studies find an association between high folate intake and increased cancer risk. However, this important area of research is often confounded by the failure of studies fail to distinguish between supplemental folic acid and natural food folate.

Prevention and treatment of mental health problems—especially depression—are topics of special interest in relationship to folate intake, and we have seen some preliminary studies linking folate deficiency to increased risk of depression.

Summary of Food Sources

As the name implies, green leafy vegetables (or foliage) are among the best sources of folate. Spinach, turnip greens, bok choy, parsley, and romaine lettuce are all rated by our system as excellent sources of folate. Other vegetables can be strong sources as well, and we see asparagus, cauliflower, broccoli and beets join the excellent group.

We also see a number of the legumes do very well for this nutrient. At the top of the list here are lentils, which achieve a rating of "excellent" for folate. In fact, among all WHFoods, lentils rank as our best source of folate! Rating "very good" as sources of folate are garbanzo beans, navy beans, kidney beans, and pinto beans.

Some, but definitely not all, fruits are important sources of folate. Papayas and strawberries are very good sources of this nutrient, while oranges, pineapple, raspberries, kiwifruit, cantaloupe, lemons and limes all rate as "good" sources of this B vitamin.

To design a whole foods diet that contains enough folate, you'll want to make sure to include plenty of minimally processed plant-based foods. If you are eating 5 cups' worth of vegetables, a couple of fresh fruits, and a legume-based meal during an average day, you are quite likely to be meeting your folate needs.

Introduction to Nutrient Rating System Chart

In order to better help you identify foods that feature a high concentration of nutrients for the calories they contain, we created a Food Rating System. This system allows us to highlight the foods that are especially rich in particular nutrients. The following chart shows the World's Healthiest Foods that are either an excellent, very good, or good source of folate. Next to each food name, you'll find the serving size we used to calculate the food's nutrient composition, the calories contained in the serving, the amount of folate contained in one serving size of the food, the percent Daily Value (DV%) that this amount represents, the nutrient density that we calculated for this food and nutrient, and the rating we established in our rating system. For most of our nutrient ratings, we adopted the government standards for food labeling that are found in the U.S. Food and Drug Administration's "Reference Values for Nutrition Labeling." Read more background information and details of our rating system.

World's Healthiest Foods ranked as quality sources of folate						
Food	Serving Size	Cals	Amount (mcg)	DRI/DV (%)	Nutrient Density	World's Healthiest Foods Rating
Lentils	1 cup	229.7	358.38	90	7.0	excellent
Asparagus	1 cup	39.6	268.20	67	30.5	excellent
Spinach	1 cup	41.4	262.80	66	28.6	excellent
Turnip Greens	1 cup	28.8	169.92	42	26.5	excellent
Broccoli	1 cup	54.6	168.48	42	13.9	excellent
Beets	1 cup	74.8	136.00	34	8.2	excellent
Romaine Lettuce	2 cups	16.0	127.84	32	36.0	excellent

Bok Choy	1 cup	20.4	69.70	17	15.4	excellent
Cauliflower	1 cup	28.5	54.56	14	8.6	excellent
Parsley	0.50 cup	10.9	46.21	12	19.0	excellent
Pinto Beans	1 cup	244.5	294.12	74	5.4	very good
Garbanzo Beans	1 cup	269.0	282.08	71	4.7	very good
Black Beans	1 cup	227.0	256.28	64	5.1	very good
Navy Beans	1 cup	254.8	254.80	64	4.5	very good
Kidney Beans	1 cup	224.8	230.10	58	4.6	very good
Papaya	1 medium	118.7	102.12	26	3.9	very good
Brussels Sprouts	1 cup	56.2	93.60	23	7.5	very good
Green Peas	1 cup	115.7	86.78	22	3.4	very good
Bell Peppers	1 cup	28.5	42.32	11	6.7	very good
Green Beans	1 cup	43.8	41.25	10	4.2	very good
Celery	1 cup	16.2	36.36	9	10.1	very good
Cabbage	1 cup	43.5	36.00	9	3.7	very good
Summer Squash	1 cup	36.0	36.00	9	4.5	very good
Strawberries	1 cup	46.1	34.56	9	3.4	very good
Tomatoes	1 cup	32.4	27.00	7	3.8	very good
Leeks	1 cup	32.2	24.96	6	3.5	very good
Fennel	1 cup	27.0	23.49	6	3.9	very good
Lima Beans	1 cup	216.2	156.04	39	3.2	good
Dried Peas	1 cup	231.3	127.40	32	2.5	good
Avocado	1 cup	240.0	121.50	30	2.3	good
Peanuts	0.25 cup	206.9	87.60	22	1.9	good
Sunflower Seeds	0.25 cup	204.4	79.45	20	1.7	good
Quinoa	0.75 cup	222.0	77.70	19	1.6	good
Winter Squash	1 cup	75.8	41.00	10	2.4	good
Oranges	1 medium	61.6	39.30	10	2.9	good
Cantaloupe	1 cup	54.4	33.60	8	2.8	good
Onions	1 cup	92.4	31.50	8	1.5	good
Collard Greens	1 cup	62.7	30.40	8	2.2	good
Pineapple	1 cup	82.5	29.70	7	1.6	good
Raspberries	1 cup	64.0	25.83	6	1.8	good
Carrots	1 cup	50.0	23.18	6	2.1	good
Beet Greens	1 cup	38.9	20.16	5	2.3	good
Mushrooms, Crimini	1 cup	15.8	18.00	5	5.1	good
Kiwifruit	1 2 inches	42.1	17.25	4	1.8	good
Kale	1 cup	36.4	16.90	4	2.1	good
Swiss Chard	1 cup	35.0	15.75	4	2.0	good
Mushrooms, Shiitake	0.50 cup	40.6	15.22	4	1.7	good
Basil	0.50 cup	4.9	14.42	4	13.3	good
Eggplant	1 cup	34.6	13.86	3	1.8	good
Mustard Greens	1 cup	36.4	12.60	3	1.6	good
Lemons and Limes	0.25 cup	13.4	12.20	3	4.1	good

World's Healthiest Foods Rating	Rule
excellent	DRI/DV>=75% OR Density>=7.6 AND DRI/DV>=10%
very good	DRI/DV>=50% OR Density>=3.4 AND DRI/DV>=5%
good	DRI/DV>=25% OR Density>=1.5 AND DRI/DV>=2.5%

Impact of Cooking, Storage and Processing

Like most water-soluble vitamins, folate can frequently be removed from foods during processing. You should expect there to be a substantial loss of folate in the manufacture of canned foods. The exact amount of folate lost depends on the food in question and the processing method used, but here are some practical examples. One cup of cooked garbanzo beans (prepared from dried beans) can provide you with over 275 micrograms of folate, while the same amount of canned garbanzo beans (by weight) is likely to provide you with about 75 micrograms. Or to use a folate-rich vegetable example, like asparagus: one cup of cooked asparagus (prepared from fresh form) can provide over 265 micrograms of folate, with the same amount of canned asparagus (by weight) providing about 170 micrograms. So as you can see, there is substantial loss of folate in both of these examples. The difference between canned and non-canned legumes is one you will want to keep in mind when enjoying the convenience of canned legumes. You can help maintain strong folate intake when using canned legumes by combining them with non-canned folate-rich foods like green leafy vegetables.

Our basic approach to food selection and preparation at WHFoods is to avoid processing as much as possible and rely instead on fresh and minimally cooked foods. Loss of folate during processing is one of the many reasons we have adopted this approach.

Occasionally, a method of food preparation can increase the level of a nutrient, and we are aware of one such example involving folate. This particular example involves conventional preparation of tofu and tempeh using microorganisms and fermentation. While folate is typically lost during the early stages of the tofu/tempeh preparation due to soaking of soybeans in water, fermentation of the soaked beans can ultimately replenish the lost folate. While neither tofu nor tempeh emerge as ranked sources of folate at WHFoods, both contain measurable amounts of folate in the 25-30 microgram per serving range.

One final note about fermentation here: we've seen studies show that fermentation of cow's milk—as would occur in production of yogurt, and especially with live cultures remaining in the final product—can also somewhat increase the milk's folate content.

Folate should be fairly stable to cold, at least over short periods of time. For example, one study found that Chinese cabbage did not lose a significant amount of folate over three weeks of refrigeration. Of course, we generally recommend enjoyment of fresh cabbage stored for a week or so at most in the crisper bin of the refrigerator.

Risk of Dietary Deficiency

As mentioned earlier, both male and female adults in the U.S. averaged well over the recommended intake level for folate in the 2009-2010 National Health and Nutrition Examination Survey (NHANES). From our perspective, however, this adequate intake of folate in terms of amount was actually inadequate in terms of food quality, since a significant amount of this folate came in the form of fortified foods, enriched foods, or folate supplements instead of whole, natural foods. We believe that your health is always better served if you are able to get the nutrients you need from whole, natural foods. If U.S. adults did not currently consume folate-fortified and folate-enriched foods, in combination with folic acid-containing supplements, they would not average adequate intake for folate! However, if you regularly enjoy our recipes, you will personally be likely to do just as well as the average U.S. adult in your food-based intake of folate, without resorting to fortification, enrichment, or supplements.

For many of our nutrients, we can design a sample daily diet to feature multiple strong sources of the nutrient and ensure good continuity over days and weeks of eating. With respect to folate, this task is especially easy. To approximate our DV of 400 mcg, you just need to have a large serving of greens . If you'd prefer, you could get within 15% of the DV by having a legume-rich meal (such as our Black Bean Chili). We have 25 recipes that rate as excellent sources of folate, most of which contain over half your DV for folate.

Other Circumstances that Might Contribute to Deficiency

Folate is more difficult to absorb and utilize than most of the other water-soluble vitamins. As such, people with bowel disease or other conditions that interfere with absorption may need to pay extra attention to folate nutrition.

Certain conditions and life stages can increase your need for folate, even when dietary supply is consistent. The most important is pregnancy. If you plan to and/or are able to become pregnant, make sure and have a look at the public health recommendations below. Breastfeeding is also a time when the need for folate increases, and it is therefore also a time of greater deficiency risk.

Many medications, including seizure medications and drugs used to treat inflammation, interfere with folate metabolism. If you are on one of these medications, you may need to work with your doctor to ensure you get enough folate.

Relationship with Other Nutrients

Folate is a member of the B complex vitamins, and like the others in this group, it will rely on the presence of the entire group to do its job effectively. Luckily, most of the B complex vitamins are found in the same plant foods that are rich in folate, so a diet rich in one is often rich in the others.

The most important exception to this rule is also the B vitamin whose role is most entwined with folate. Vitamin B12, which can only be made by microorganisms and which typically only accumulates in animal foods, fermented plant foods, and mushrooms works closely with folate in many of its different roles. Because folate is provided by a much larger variety of foods than B12, and because a wider variety of foods are typically fortified with folate and not B12, it is sometimes possible to get very large amounts of folate in comparison to B12. This type of imbalanced intake can be problematic since excessive amounts of folate can make deficiency of B12 more difficult to detect through standard lab tests. If left undetected, longstanding B12 deficiency can lead to sometimes irreversible health problems.

Luckily, the amounts of folate needed to create this type of problem is large and would be virtually impossible to obtain from whole, natural foods. You could, however, create this type of folate-to-B12 imbalance from a routine combination of fortified foods and supplemental folic acid. As you'll see below in the Risk of Dietary Toxicity section, this safety factor provided by whole foods versus fortified foods and supplements is the reason that an upper limit was set by the National Academy of Sciences for intake of folate from fortified foods and supplements, but not for intake of folate found in natural, non-fortified foods.

The pathways that utilize folate and vitamin B12 are also dependent on vitamin B6 and riboflavin for proper functioning. Compared to folate and vitamin B12, however, these additional two B vitamins are less likely to be deficient to the point of creating a problem.

Risk of dietary Toxicity

There is no known risk of toxicity from excessive naturally occurring folate from foods. This is good news, since the diets highest in folate tend to be those highest in vegtables, legumes, and other highly desirable foods that belong in most healthy meal plans.

It would, however, be very easy to go above the Tolerable Upper Intake Limit (UL) of 1000 mcg of added or supplemental folic acid on a regular basis. (Note: this UL is set for all individuals 19 years and older, with the exception of women under 19 years of age who are pregnant or breastfeeding. For women in that category, the UL is 800 mcg.) For example, if you take a multiple vitamin supplement that contains 400 mcg of folic acid, and on top of that you add an energy bar that contains 15 micrograms, and a breakfast cereal fortified with 30 micrograms, you'll have 445 micrograms of folate or 45% of the UL *before* you start counting your primary list of foods for the day. One cup of lentils, one cup of broccoli, and 2 tablespoons of peanuts would put you over the UL at 1,059 micrograms.

The level of folate intake describe above is unlikely to cause problems on an occasional basis. However, if you plan to routinely consume folate-fortified foods and take supplements providing large amounts of folic acid, you may want to talk with a nutritionist and/or healthcare provider to help avoid possible problems with B vitamin balance given regular high intake of this B vitamin.

One additional note about the upper limits set for folate intake: for children 1-3 years of age, the UL is 300 micrograms; for children 4-8, the UL is 400 micrograms; for 9-13 year olds, it is 600 micrograms; and for 14-18 year olds, it is 800 micrograms.

Disease Checklist

- Pregnancy
- Birth defects (prevention)
- Depression
- High blood pressure
- Cancer prevention
- Cognitive decline

- Anemia
- Gingivitis
- Osteoporosis
- Ulcerative colitis
- Psoriasis

Public Health Recommendations

In 1998, the National Academy of Sciences (NAS) published Dietary Reference Intake (DRI) guidelines for folate. These guidelines included Recommended Dietary Allowances (RDAs) for all persons one year and older. The folate recommendations were established in terms of micrograms of Dietary Folate Equivalents (or micrograms DFE) in order to adjust for intake of folate from fortified foods and supplements. For infants under one year of age, the DRIs were established as Adequate Intake (AI) levels rather than RDAs. A summary of these recommendations appears below:

- 0-6 months: 65 mcg DFE
- 6-12 months: 80 mcg DFE
- 1-3 years: 150 mcg DFE
- 4-8 years: 200 mcg DFE
- 9-13 years: 300 mcg DFE
- 14+ years: 400 mcg DFE
- Pregnant women: 600 mcg DFE
- Lactating women: 500 mcg DFE

The National Academy of Sciences also recommended that any woman who could become pregnant consume 400 mcg of folic acid daily from either a supplement or from fortified foods in addition to the naturally occurring folate in the diet. In 1991, the Centers for Disease Control (CDC) recommended women who have previously had a child with a neural tube defect should take 4000 mcg of supplemental folic acid when starting pregnancy planning.

Tolerable Upper Limits, or ULs for folate were also established by the NAS. The ULs do not apply to naturally occurring folate in food. (In other words, there was no limit set on the amount of natural food folate found to be safe.) Instead, the ULs only apply to folate obtained from fortified foods or supplements. Below is a summary of the ULs:

- Infants under 1 year of age: not established
- Children 1-3 years: 300 micrograms
- Children 4-8 years: 400 micrograms
- 9-13 year olds: 600 micrograms
- 14-18 year olds: 800 micrograms
- Individuals 19+ years: 1,000 micrograms
- Women under 19 years who are pregnant or breastfeeding: 800 micrograms

The Daily Value (DV) recommendation for folate is 400 mcg per 2000 calories. This is the value we use to calculate food rankings in all of our food and nutrient charts.

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The World's Healthiest Foods

World's Healthiest Foods rich in iodine		
Food	**Cals**	**DRI/DV**
Sea Vegetables	11	500%
Scallops	126	90%
Cod	96	88%
Yogurt	149	47%
Shrimp	135	31%
Sardines	189	24%
Salmon	158	21%
Cow's milk	74	19%
Eggs	78	18%
Tuna	147	15%

Basic Description

Iodine is a fascinating mineral, and it's somewhat surprising how relatively little research has been done on the role of iodine in human health, in comparison to the amount of research that has been done on the role of iodine in the environment. Although we usually keep our website nutrient profiles focused closely on food and health, we would like to provide you with a little bit of information about iodine outside of a strict health context. This broader context may actually end up shedding some light on future research about iodine and health.

Scientists already understand how iodine plays a multi-faceted role in the environment and serves as a key mineral in oceans, soil, and atmosphere. The stability of the earth's ozone layer, for example, is known to have a relationship to iodine levels in the atmosphere. Atmospheric iodine, in turn, is known to be related to iodine balance in the oceans and in the soil. Scientists also know that iodine concentrations in the atmosphere influence a wide range of oxygen-based reactions. Iodine has also been studied within the context of soil and plant health. Based on research in this area, we know that in some plants—for example, lettuce—iodine can help to offset stresses that get placed on the plants to due excess presence of salt in the soil (salinity stress).

Unfortunately, these roles of iodine in oxygen-based reactions and in balancing mineral levels (especially when sodium, potassium, and chlorine are involved) have not studied in human health as extensively as they have been studied in health of the environment, and we will need to wait on future studies for a clear understanding of these potential iodine roles in human health. However, one area of human health where we do not need to wait for more information is the area of thyroid gland function. The role of iodine in thyroid gland function has been studied in depth, and we will be telling you much more about this role later in this profile.

Approximately 30% of our WHFoods contain some iodine, and you will find most food groups represented in this overall list of iodine-containing foods. In the vegetables group, for example, you will find sweet potatoes, onions, and spinach. In the fruit group, you will find strawberries, banana, and cantaloupe. In the grains you will find barley, and in the nuts you will find peanuts. (Although we list peanuts under "Nuts & Seeds" on our website, they are technically classified as legumes). Yet despite the presence of iodine in this diverse group of foods, it is difficult to get our recommended daily amount of 150 micrograms unless you consume foods from two food groups *not* listed above. These two groups are Seafood and Eggs & Dairy. In fact, only 11 of our WHFoods rank as good, very good, or excellent sources of iodine, and these two groups (Seafood and Eggs & Dairy) account for over 90% (10/11) of all of our iodine-rich foods. We'll be providing you with much more information about this iodine-food relationship in our Summary of Food Sources section.

At one point in time, iodine deficiency was fairly common in most of the northern part of the United States. This "goiter belt" included New England, the upper Great Lakes region, and the Pacific Northwest. The combination of iodine-depleted soils and lack of access to (or lack of acceptance of) seafoods left up to 30% of the population with severe iodine deficiency and its telltale goiter. ("Goiter"—a word that comes from the Latin "*guttur*" meaning "throat"—is a non-technical term that refers to enlargement of the thyroid grand. While iodine deficiency is one of the reasons that the thyroid gland can become enlarged, it does not always become enlarged following iodine deficiency and it can become enlarged for other reasons not involving dietary iodine.)

Starting in the early 20th century, an Ohio doctor aptly named David Marine began experimenting with adding iodine to local diets by way of iodized salt. (We say "aptly" here since seafoods are such an important dietary source of iodine.) By the 1920s, widespread consumption of this fortified salt in the U.S. had largely eliminated widespread iodine deficiency. We will discuss this issue of iodized table salt—and its potential role in your meal plan—later in this article.

Role in Health Support

As described earlier, even though researchers know a good bit about iodine in relationship to the environment, less is known about other health support roles for iodine in the body. However, one area in which we are not lacking for information is the role of iodine in thyroid health.

Thyroid Hormone Production

Iodine is a key component of the hormones made in the thyroid gland. These hormones are absolutely critical to human health, helping to control energy production and utilization in nearly every cell of the body.

The balance of iodine in the thyroid gland is tricky, and both too much and too little iodine can slow down the production of hormones. This is not a situation where more is always better. Our WHFoods recommended daily intake level of 150 micrograms is a level that makes the most sense to us as a general public health recommendation for preserving balanced production of thyroid hormones. For most people, we would predict that falling far below this level or greatly exceeding it would potentially increase the risk of imbalanced thyroid hormone production.

Summary of Food Sources

When it comes to iodine, one food stands so far above the rest that the chart at the top of the page almost looks like a misprint. Some sea vegetables contain as much as 500% of the Daily Value (DV) per serving.

This is only true, however, for some sea vegetables. A good rule of thumb is that the brown sea vegetable species—for instance, kelp and wakame—are richer in iodine than the red forms. Still, we view sea vegetables (regardless of variety) as a potentially concentrated source of iodine, and anyone consuming 1 tablespoon or more of these foods on a daily basis mighty want to evaluate their total daily intake of iodine to make sure it does not exceed the Tolerable Upper Limit (UL) established by the National Academy of Sciences for adults 19 and older of 1,100 micrograms. For more on iodine and how to pick sea vegetables, read our profile on these interesting and useful foods.

Sea vegetables like kelp and wakame are not the only sea-based foods rich in iodine, however. All six of our seafoods rank as good, very good, or excellent sources of this mineral. In the excellent category you will find scallops and cod. In the very good category you will find shrimp. And in the good category you will find tuna, salmon, and sardines. Both cod and scallops will provide you with nearly 90% of the daily recommended amount for iodine in a single 4-ounce serving. We would also like to note that many fish not profiled on our website contain significant amounts of iodine, generally falling into the range of 25-140 micrograms per 4-ounce serving. As a general rule (that does have numerous exceptions, however), shellfish are more concentrated in iodine than finfish.

Two of our dairy foods—cow's milk and yogurt—as well as eggs rank as very good sources of iodine. You can get about 20% of your daily iodine from 4 ounces of cow's milk, 1 egg, or 1/2 cup of yogurt.

The WHFoods that we have described above account for all but one of our ranked food sources of iodine. The only source we haven't mentioned are strawberries, which rank as a very good source and provide about 13 micrograms per cup. (This ranking is largely due to the fact that strawberries are a high-water and low-calorie fruit, providing only 46 calories per cup.) While you would not want to rely on strawberries for your iodine intake, it would not be unreasonably to expect strawberries to provide about 10% of the iodine you need on any given day when you choose to eat them.

As described earlier, you can find foods in the vegetable group (like sweet potatoes, onions, and spinach), other foods in the fruit group (like bananas and cantaloupe), and foods in the grain group (barley) as well as the nuts group (peanuts, which are technically classified as legumes rather than nuts) that provide iodine. Like strawberries, however, you would not want to rely heavily on these foods to provide you with your daily iodine requirement. Conservatively speaking, including these non-seafood, non-dairy foods in your day's food would most likely provide you with about 5-30% of the iodine you need.

As you can see from the above food summary, people who enjoy eating seafood on a near-daily basis have a good chance of meeting their daily iodine needs because they will often be able to get 50% of more of those needs from the seafood alone. A

single serving of dairy foods on the same day might move this percentage up closer to 75%, and other foods would be able to make up the remainder.

For people who completely avoid seafood in their meal plan, iodine needs become a little bit trickier to meet. One meal plan addition worthy of consideration here would be to choose sea vegetables as a recipe component. Since 1 tablespoon of a sea vegetable like dulse can provide five times the daily iodine requirement all by itself, you could enjoy a recipe with this amount of sea vegetable and meet your iodine requirement over a five-day time period. Our 5-Minute Miso Soup with Dulse recipe will provide you with exactly that amount per serving. Dried kelp flakes or other forms of dried sea vegetables can be sprinkled on top of many dishes, and it is important to remember that it only takes one-fifth of a tablespoon—just a little bit more than half a teaspoon—to meet your recommended daily iodine level.

Of course, another alternative available to everyone is iodized salt. Iodized salt is a fortified form of table salt that has been processed to contain significant amounts of iodine. The general government standard for fortification of salt with iodine is 76-77 micrograms of iodine per gram of salt. However, many iodized salts don't actually end up containing this much iodine. An average marketplace range seems to be closer to 45-50 micrograms per gram. Still, at 6 grams per teaspoon, this level of 45-50 micrograms would mean that 1 teaspoon of iodized salt would be likely to contain at least 270-300 micrograms of iodine and 1/4 teaspoon would be likely to contain at least 67-75 micrograms. So it is easy to see how 1/4 teaspoon of iodized salt could provide about half of a person's daily recommended iodine. (This same 1/4 teaspoon would provide about 580 milligrams of sodium, or about 12% of the Daily Value.)

As a general rule, we always prefer whole, natural foods as a source of all nutrients, and there simply isn't any form of iodized salt that is whole and natural. By definition, iodized salt is a processed, fortified ingredient. It is possible, of course, to purchase iodized sea salt, but even in this situation, the sea salt has been fortified with iodine during processing. (While iodine is naturally present in sea salts along with other minerals, it is not present in amounts that would qualify the salt to be labeled as "iodized.")

In addition to our preference for whole, natural foods as a source of all nutrients, we also emphasize the pleasures of herbs, spices, and natural flavors found in fresh foods. The idea of substituting salt for the true pleasures of good cooking does not make sense to us. (That's why you will find many of our recipes to be devoid of table salt as an ingredient, and our ingredients followed by the option, "salt and pepper to taste.")

At the same time, we are not aware of any special problems related to the process of fortifying salt with iodine. In addition, we realize that many people rely on small amounts of iodized salt to boost up an otherwise deficient iodine intake level. Especially for persons who avoid seafood and dairy in their meal plans, iodized salt might make a logical addition to meet daily iodine needs. Obviously, the decision about whether to include iodized salt in a meal plan is a personal decision. From our perspective, it could be a very sensible choice, depending on all of the circumstances involved. We would, however, caution anyone who has been placed on a salt-restricted diet, or who suspects that they might fall into the minority of U.S. adults who are salt-sensitive in terms of blood pressure regulation, to talk over their best options for meeting daily iodine needs with their healthcare provider.

We would like to add one final note here on the relationship between salt and iodine intake. Processed foods in the U.S. have a well-deserved reputation for being overly high in salt. This trend has not been limited to fast foods or foods at a corner grocery. Many popular canned soups, frozen vegetables, and other widely enjoyed pre-packaged foods contain large amounts of salt. However, the salt added to processed foods is typically not iodized salt that has been fortified with iodine. For this reason, it simply is not correct to assume that consumption of a processed, high-sodium food is likely to provide you with the iodine you need, even if you venture out into processed, prepackaged foods as a regular part of your diet.

Introduction to Nutrient Rating System Chart

In order to better help you identify foods that feature a high concentration of nutrients for the calories they contain, we created a Food Rating System. This system allows us to highlight the foods that are especially rich in particular nutrients. The following chart shows the World's Healthiest Foods that are either an excellent, very good, or good source of iodine. Next to each food name, you'll find the serving size we used to calculate the food's nutrient composition, the calories contained in the serving, the amount of iodine contained in one serving size of the food, the percent Daily Value (DV%) that this amount represents, the nutrient density that we calculated for this food and nutrient, and the rating we established in our rating system. For most of our nutrient ratings, we adopted the government standards for food labeling that are found in the U.S. Food and Drug Administration's "Reference Values for Nutrition Labeling." Read more background information and details of our rating system.

World's Healthiest Foods ranked as quality sources of iodine						

Food	Serving Size	Cals	Amount (mcg)	DRI/DV (%)	Nutrient Density	World's Healthiest Foods Rating
Sea Vegetables	1 TBS	10.8	750.00	500	829.5	excellent
Scallops	4 oz	125.9	135.00	90	12.9	excellent
Cod	4 oz	96.4	132.00	88	16.4	excellent
Yogurt	1 cup	149.4	71.05	47	5.7	very good
Shrimp	4 oz	134.9	46.00	31	4.1	very good
Cow's milk	4 oz	74.4	28.06	19	4.5	very good
Eggs	1 each	77.5	27.00	18	4.2	very good
Strawberries	1 cup	46.1	12.96	9	3.4	very good
Sardines	3.20 oz	188.7	36.00	24	2.3	good
Salmon	4 oz	157.6	32.00	21	2.4	good
Tuna	4 oz	147.4	23.00	15	1.9	good

World's Healthiest Foods Rating	Rule
excellent	DRI/DV>=75% OR Density>=7.6 AND DRI/DV>=10%
very good	DRI/DV>=50% OR Density>=3.4 AND DRI/DV>=5%
good	DRI/DV>=25% OR Density>=1.5 AND DRI/DV>=2.5%

Impact of Cooking, Storage and Processing

Iodine is stable to storage and many types of processing. For example, we don't see loss of iodine in sea vegetables, even if stored for long periods of time. You do not need to choose or store your iodine-rich foods in a special way to protect against loss. We do recommend, however, that you take a quick glance at the sea vegetables profile to help you select the best types for your nutritional and culinary needs.

As you cook iodine-rich foods, you will extract a significant portion of the iodine into the cooking water. This can be a good thing for nutrition, for example when you are making soup stock. Boiling sea vegetables for 15 minutes can extract from half to almost all its iodine content into the stock, making this soup now a great source of iodine nutrition.

Although becoming less popular, the use of iodine-containing dough conditioners to help to strengthen integrity of bread still remains a common practice. The iodine used in this processwill be listed on the food label as calcium iodate.

Risk of Dietary Deficiency

The risk of iodine deficiency is substantial in the United States and has been on the rise. The average urinary iodine level—a good measure of recent dietary iodine intake—has dropped by more than half since the 1970s. Of course, we are talking about a very broad population-level trend here, in a country where processed, prepackaged foods play a major role in the average U.S. adult meal plan.

The reason we see iodine levels dropping in the population is two-fold. One is that within the world of commercial baking, many bread manufacturers have moved away from iodine-containing compounds to keep dough fresh. But a bigger change is that the average U.S. household is doing less and less home cooking and resorting more and more often to prepackaged foods, ready-to-eat foods, and restaurant eating (including fast food eating). As mentioned earlier, even though many prepackaged foods are high in sodium, the salt added to these foods has not necessarily been fortified with iodine.

Still, there is a good bit of unpredictability in the iodine content of prepackaged and ready-to-eat foods. Some food preparers use salt that is iodized, including some fast food restaurants. But because the level of iodine in "away-from-home" foods can be so unpredictable, we recommend that you focus on obtaining iodine from whole, natural foods. The food sources of iodine section above should help you figure out what combination of whole, natural foods will work best for you.

Perhaps most concerning is the recent finding that the average pregnant woman in the United States has substandard iodine nutrition. Iodine—as a constituent of thyroid hormone—is critical to the developing nervous system, and low iodine levels in

children are associated with impaired development.

Counter-balancing this concern is evidence from the most recent National Health and Nutrition Examination Survey which shows that this drop in iodine intake has stabilized. So while we need to do a better job of making sure at-risk people—especially pregnant women—get enough iodine, at least the public health problem is not continuing to get worse.

Other Circumstances that Might Contribute to Deficiency

Iodine content of soils varies by region. At one point in time, when food didn't travel very far to get to the plate, the low-iodine region of the Great Lakes region was referred to as the "goiter belt" due to problematic iodine nutrition. Because food travels much more in our modern supply chain, regional differences in soil iodine content don't play as prominent a role as in earlier periods of U.S. history.

Because fish and dairy foods are among our richest sources of iodine, vegans (individuals who eat no animal foods products whatsoever) appear to be at increased risk of iodine deficiency. A 2011 study found that the average U.S. vegan had a urinary iodine level that would be considered deficient. Even among this at-risk group, however, we did not see thyroid disease related to the low-iodine diets. Note that vegetarians who include milk and eggs in their diets end up with iodine levels very similar to the entire population.

There are compounds called thiocyanates in some commonly consumed foods. At high concentrations, these chemicals can interfere with the uptake of iodine into the thyroid gland, making a person seem like they have iodine deficiency, when they may not. The common thiocyanate containing foods include cassava, soy, and *Brassica* family vegetables. Tobacco smoke also contains thiocyanates.

The most commonly reported version of thiocyanate-related disease is seen in areas of Africa where cassava root is an important dietary staple. In the U.S., we occasionally see this issue related to soy-based infant formulas, but even then almost exclusively in infants born with thyroid disease

Contrary to what we've read elsewhere on the Internet, we believe that at the amounts we consume these foods regularly, there is not compelling evidence of significant risk. For example, a 2011 study found no association between reported intake or soy or blood concentrations of soy nutrients and problems with thyroid function in pregnant women, a group otherwise at high risk for thyroid disease. For more on this topic, click through to this article about thiocyanate containing foods and thyroid disease.

The most likely thyroid disruptors in the environment are not in foods, but in medications or man-made toxins. Lithium (used to treat bipolar disorder) and phenylbutazone (used as an anti-inflammatory) are examples of drugs that can impair iodine nutrition.

Perchlorate, a chemical used in rocket fuel, is an environmental toxin found in water supplies in the U.S. at varying concentrations. It can also impair uptake of iodine into the thyroid. According to the Natural Resources Defense Council, if you have perchlorate in your water, you'll need a reverse osmosis filter to effectively remove it.

Relationship with Other Nutrients

Selenium is a necessary co-factor for a family of enzymes called iodothyronine deiodinase. These enzymes are responsible for activation and deactivation of thyroid hormones. As such, deficiency of selenium may either exacerbate iodine deficiency, or even mimic some of the symptoms.

We also know that deficiency of iron makes the thyroid dysfunction seen in iodine deficiency worse. At this point in time, we don't have a clear explanation why. We do know, however, that this is a big public health problem worldwide, especially in the developing world.

Risk of dietary Toxicity

There is an acute toxicity that can occur from excessive iodine intake that leads to mouth pain, nausea, and vomiting. This almost never occurs from dietary iodine alone, and if it did, it would require that another serious medical condition (e.g., kidney failure) be present.

The Tolerable Upper Intake Limit (UL) of 1,100 mcg / day is set by the National Academy of Sciences in its Dietary Reference Intakes (DRIs) to prevent more chronic and subtle health problems related to iodine overconsumption. Oddly, diets high in

iodine are associated with increased size and decreased function of the thyroid gland, the very same symptoms we see with too little iodine. We would note here that the UL of 1,100 micrograms applies to adults ages 19 and older. For teens 14-18 years of age, the UL is set lower at 900 micrograms, and for teens 9-13 years, at 600 micrograms. For children 4-8 years of age, the iodine UL is 300 micrograms, and for children 1-3 years, it is 200 micrograms. You can review the full range of DRIs for iodine in our Public Health Recommendations section.

Luckily, diets that routinely go above the UL for iodine appear to be rare in the US, as well as throughout the world. The easiest way to get to iodine excess would be heavy consumption of sea vegetables, which can contain up to four times the UL in a single one-quarter ounce serving. For best thyroid health, we would consider the most iodine-rich sea vegetables a "sometimes" food rather than a daily indulgence.

Heavy use of iodized salt could also be a contributor toward excess iodine consumption. Iodine can be added to salt at amounts up to 77 mcg per gram. If a person was consuming 5,000 mg of sodium from iodized salt—a fairly standard sodium intake for 25% of adult U.S. males—that person might be getting just shy of 1,000 mcg of iodine per day. Of course, this example makes the unlikely assumption that all the salt in a person's diet had been fortified with iodine. As described earlier, this situation would be unlikely, since most processed, high-sodium foods have not been processed using iodized salt.

Disease Checklist

- Goiter
- Hypothyroidism
- Skin infection
- Fibrocystic breast disease

Public Health Recommendations

In 2001, the National Academy of Sciences established a set of Dietary Reference Intakes (DRIs) for iodine. This set of recommendations included Recommended Dietary Allowances (RDAs) for all individuals over 1 year of age, and Adequate Intakes (AIs) for infants under 1 year. These DRI recommendations are as follows.

- 0-6 months: 110 mcg
- 6-12 months: 130 mcg
- 1-8 years: 90 mcg
- 9-13 years: 120 mcg
- 14+ years: 150 mcg
- Pregnant women: 220 mcg
- Lactating women: 290 mcg

The DRI report also established a Tolerable Upper Intake Levels (ULs) for iodine. These ULs vary with age. For adults 19 years and older, the UL is set at 1,100 micrograms per day. For teens 14-18 years of age, the UL is set lower at 900 micrograms, and for teens 9-13 years, at 600 micrograms. For children 4-8 years of age, the iodine UL is 300 micrograms, and for children 1-3 years, it is 200 micrograms. The iodine ULs are intended as average maximum limits. Occasionally going above the UL is not generally believed to be health concern.

The Daily Value (DV) for iodine is 150 mcg. This is the value that you will see on food and supplement labels, and the value that we have chosen as our WHFoods daily recommended amount.

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The World's Healthiest Foods

World's Healthiest Foods rich in iron		
Food	Cals	DRI/DV
Soybeans	298	49%
Lentils	230	37%
Spinach	41	36%
Sesame Seeds	206	29%
Garbanzo Beans	269	26%
Lima Beans	216	25%
Olives	155	25%
Navy Beans	255	24%
Swiss Chard	35	22%
Kidney Beans	225	22%

Basic Description

Probably the best known nutrition fact about iron is that meats—particularly red meats—are rich in iron. You will see some familiar animal foods on our list of iron sources below.

While this is true, it is also true that a number of plant foods are also rich in iron. It may come as a surprise that researchers have found that people eating plant-based diets eat as much or more iron as people who regularly rely on animal foods. And, you'll see that our list of excellent iron sources is largely dominated by plant foods.

Without question, more human health problems worldwide are caused by iron deficiency than by lack of any other nutrient. Less well known is the fact that excessive iron stores are also responsible for a large burden of illness worldwide. As such, iron is a very important nutrient to understand not only for researchers and nutritionists but everyone, since we need to be aware of finding the right iron balance from our foods.

Five of the World's Healthiest Foods rank as excellent sources of iron and nine foods rank as very good sources. Additionally, 30 foods rank as good sources. Added together, over one-third rank as good, very good, or excellent sources of iron.

Our 7 day Healthiest Way of Eating Plan will provide you with a week's worth of recipes that contain iron-rich and largely plant-based meal strategies. Once you learn to identify iron-rich foods, you'll be able to use our recipe planners to learn new and exciting ways to include them in your cooking.

Role in Health Support

Enhances Oxygen Transport

All of the tissues in our body need a near constant supply of oxygen to maintain life. We maintain this oxygen delivery by the red cells in our blood. These have an iron-containing protein called hemoglobin, which is a perfect transporter for oxygen, in that it both picks up and releases oxygen in an exact and targeted way.

The average man has about 2 grams of iron in his blood cells at any given time while women have about 1.6 grams. If the dietary iron intake falls below daily needs and this storage amount goes down, the ability to tolerate bursts of exercise will deteriorate. The reduction in blood count related to having low iron stores (or other nutrient deficiencies, including of vitamin B12, folate, copper, and vitamin A) is called anemia.

Supports Energy Production

In addition to the key role iron plays in transporting oxygen to tissues, it also is necessary to support proper metabolism for muscles and other active organs. Almost all of the cells in our body burn dietary calories to create energy through a process that requires iron. When iron stores get low, this process gets compromised, and generalized fatigue can occur.

This lag in energy production tends to occur earlier than changes in blood cell production, so the muscle fatigue and changes in concentration are likely to be noticeable long before laboratory testing shows low blood cell production.

Summary of Food Sources

You may be surprised to see no animal foods listed among our excellent or very good sources of iron. There are two related reasons for this result.

First, as we discussed above, it is a common misconception that plant foods are not rich sources of iron. In fact, many plant foods contain more than 10% of a daily iron requirement per serving. Some—lentils and spinach, for example—contain as much as one third of the daily requirement.

Second, plant foods tend to have fewer calories per serving than animal foods. Since we base our food ratings on nutrient richness (or amount of nutrient per calorie), the least energy dense foods look the best in our assessment model.

Among plant foods, legumes and leafy green vegetables are consistently among our best sources. Several spices are surprisingly strong sources of iron. Whole grains can also be good contributors to iron nutrition.

While not included as one of our World's Healthiest Foods, blackstrap molasses—the thick syrup that remains after sugars have been extracted from sugar cane through boiling and filtering—provides about 1 milligram of iron per teaspoon. This amount is somewhat unusual among sweeteners and much greater than the amount found in a teaspoon of honey, maple syrup, or brown sugar.

All of this is not to say that animal foods are not concentrated sources of iron, as well. Many of the animal foods represented in the World's Healthiest Foods list contain at least 2 mg of iron per serving. Included among these are lamb , sardines, and grass-fed beef.

Introduction to Nutrient Rating System Chart

In order to better help you identify foods that feature a high concentration of nutrients for the calories they contain, we created a Food Rating System. This system allows us to highlight the foods that are especially rich in particular nutrients. The following chart shows the World's Healthiest Foods that are either an excellent, very good, or good source of iron. Next to each food name, you'll find the serving size we used to calculate the food's nutrient composition, the calories contained in the serving, the amount of iron contained in one serving size of the food, the percent Daily Value (DV%) that this amount represents, the nutrient density that we calculated for this food and nutrient, and the rating we established in our rating system. For most of our nutrient ratings, we adopted the government standards for food labeling that are found in the U.S. Food and Drug Administration's "Reference Values for Nutrition Labeling." Read more background information and details of our rating system.

World's Healthiest Foods ranked as quality sources of iron						
Food	Serving Size	Cals	Amount (mg)	DRI/DV (%)	Nutrient Density	World's Healthiest Foods Rating
Spinach	1 cup	41.4	6.43	36	15.5	excellent
Swiss Chard	1 cup	35.0	3.96	22	11.3	excellent
Cumin	2 tsp	15.8	2.79	16	17.7	excellent
Parsley	0.50 cup	10.9	1.88	10	17.2	excellent
Turmeric	2 tsp	15.6	1.82	10	11.7	excellent
Beet Greens	1 cup	38.9	2.74	15	7.0	very good
Collard Greens	1 cup	62.7	2.15	12	3.4	very good
Bok Choy	1 cup	20.4	1.77	10	8.7	very good
Asparagus	1 cup	39.6	1.64	9	4.1	very good
Mustard Greens	1 cup	36.4	1.22	7	3.4	very good
Turnip Greens	1 cup	28.8	1.15	6	4.0	very good
Leeks	1 cup	32.2	1.14	6	3.5	very good
Chili Peppers	2 tsp	15.2	0.93	5	6.1	very good
Romaine Lettuce	2 cups	16.0	0.91	5	5.7	very good

Soybeans	1 cup	297.6	8.84	49	3.0	good
Lentils	1 cup	229.7	6.59	37	2.9	good
Sesame Seeds	0.25 cup	206.3	5.24	29	2.5	good
Garbanzo Beans	1 cup	269.0	4.74	26	1.8	good
Lima Beans	1 cup	216.2	4.49	25	2.1	good
Olives	1 cup	154.6	4.44	25	2.9	good
Navy Beans	1 cup	254.8	4.30	24	1.7	good
Kidney Beans	1 cup	224.8	3.93	22	1.7	good
Black Beans	1 cup	227.0	3.61	20	1.6	good
Pinto Beans	1 cup	244.5	3.57	20	1.5	good
Tofu	4 oz	164.4	3.02	17	1.8	good
Pumpkin Seeds	0.25 cup	180.3	2.84	16	1.6	good
Green Peas	1 cup	115.7	2.12	12	1.8	good
Brussels Sprouts	1 cup	56.2	1.87	10	3.3	good
Beets	1 cup	74.8	1.34	7	1.8	good
Kale	1 cup	36.4	1.17	7	3.2	good
Broccoli	1 cup	54.6	1.05	6	1.9	good
Cabbage	1 cup	43.5	0.99	6	2.3	good
Thyme	2 TBS	4.8	0.84	5	17.3	good
Green Beans	1 cup	43.8	0.81	5	1.9	good
Oregano	2 tsp	5.3	0.74	4	14.0	good
Basil	0.50 cup	4.9	0.67	4	13.7	good
Summer Squash	1 cup	36.0	0.65	4	1.8	good
Fennel	1 cup	27.0	0.64	4	2.4	good
Black Pepper	2 tsp	14.6	0.56	3	3.8	good
Sea Vegetables	1 TBS	10.8	0.56	3	5.2	good
Cloves	2 tsp	11.5	0.50	3	4.3	good
Tomatoes	1 cup	32.4	0.49	3	1.5	good

World's Healthiest Foods Rating	Rule
excellent	DRI/DV>=75% OR Density>=7.6 AND DRI/DV>=10%
very good	DRI/DV>=50% OR Density>=3.4 AND DRI/DV>=5%
good	DRI/DV>=25% OR Density>=1.5 AND DRI/DV>=2.5%

Impact of Cooking, Storage and Processing

Iron in animal foods appears to be very resilient to different methods of cooking. Minor changes may occur to the absorbability of iron, with fully cooked meats having slightly more iron in its most absorbable forms. This is probably not terribly important to overall nutrition, however, as the iron from animal foods is already more available on average than that from plant sources.

In contrast, the iron in plant foods is much more likely to be pulled out in the processing or cooking of foods. Whole grains, by way of example, can lose up to three-quarters of their iron content when their outer layers are removed during the production of refined flours. Avoiding this loss of nutrients is one of the reasons we recommend consumption of grains in their whole form—and not only grains but grain flours as well. Unless a bread label states "100% whole grain" (or "100% whole wheat" in the case of one specific grain like wheat), it is best to assume that the grains have been refined and that nutrients have been lost.

In addition, iron can be removed from plant foods by way of the water in which foods are cooked. For instance, boiling spinach for over three minutes in a large pot removes almost 90% of iron from the leaves. To minimize iron loss from cooking, we recommend shorter cooking times and the use of smaller amounts of water..

Cast iron cookware can release relevant amounts of absorbable iron into foods. This amount is likely to be a milligram or two in a meal prepared under most circumstances, but may provide far greater amounts under certain conditions. In particular, more acidic foods appear to pull iron from cookware more efficiently. This cookware-provided iron appears to be absorbable as well, and in some studies, researchers have been able to link health benefits with the use of iron cookware.

Risk of Dietary Deficiency

There is currently some debate in the research world about how to define iron deficiency. Many researchers believe that iron deficiency is only important when it causes low blood counts. This is indicative of a severe deficiency and will potentially take years of an iron-deficient diet to develop.

Recent research, however, suggests that symptoms related to iron deficiency—specifically fatigue, muscle weakness, and excessive menstrual blood flow—can occur at iron storage levels seen in women with normal blood counts.

The risk of iron deficiency in women is substantial. In fact, according to the World Health Organization, iron deficiency is the most common nutrient-related condition in the world.

In the U.S., the numbers are a little more encouraging, but iron deficiency still affects about 10% of women of childbearing age. Symptomatic iron deficiency is quite rare in men and post-menopausal women.

Young children are the other major at-risk group for iron deficiency, with close to 15% of kids developing deficiency by age 2. These numbers tend to improve until the rapid period of growth in adolescence.

Although some popular sources suggest otherwise, researchers have not consistently found that vegetarian or largely plant-based diets lead to significant increases in the risk of iron deficiency anemias. In fact, at least one research group found that the intake of iron across the US population was higher in people that did not include meat in their diet.

As an example of iron richness in a plant-based diets, consider two of our plant-based recipes: Spicy Healthy Sautéed Tofu and Black Bean Chili. are two of our all-plant recipes that provide roughly 50% of the daily requirement for iron.

Other Circumstances that Might Contribute to Deficiency

Increased blood loss, including from blood donation, will increase your daily iron needs. Up to 50% of repeat female blood donors, and 20% of males, have evidence for compromised iron status on routine screening tests.

Endurance exercise can increase iron losses by up to 50% each day. This is a commonly reported problem, particularly in younger women. A couple of iron-packed recipes that might be particularly good for training time include Oyster and Clam Chowder and Broiled Rosemary Chicken over Puréed Lentils and Swiss Chard.

Gastrointestinal problems, including malabsorption diseases and low stomach acid production, can impair iron absorption. In people with autoimmune intestinal disease, for instance, the correlation between dietary iron intake and risk of low iron stores is much stronger than in the rest of the population.

Note that in each of these risk groups, dietary iron should still be sufficient to keep stores in a healthy range, as long as you are careful to regularly include iron-rich foods in your daily diet. In fact, adding extra sources of iron in the form of fortified foods or supplements may make gastrointestinal symptoms worse for some people.

Relationship with Other Nutrients

Consuming vitamin C together with iron-containing meals can increase or optimize iron absorption. In fact, adding 50 milligrams of vitamin C—about the amount found in one-half of a grapefruit—to an iron-rich meal may make it possible to triple the absorption of iron. Put in another way, if vitamin C deficiency is severe, it may be necessary to address this issue before iron stores can be restored to normal. Note that the effect of vitamin C on iron absorption is much stronger on iron from plant foods than on animal foods.

Advanced deficiency of vitamin A can impair the ability to use iron to make red blood cells. For this reason, researchers have been exploring combined vitamin A and iron interventions in many parts of the non-industrialized world. The level of vitamin A deficiency necessary to affect iron nutrition needs to be severe, however, and does not appear to be common in the industrialized world.

Copper is necessary to mobilize iron from storage for use in blood cells and other areas. Because of this, deficiency of copper may play a role in anemia. Legumes like soybeans and lentils are simultaneously high in iron and copper, and as such may be a particularly good choice for keeping a strong supply of both of these at-risk minerals.

Oddly, although in short-term experiments calcium and iron compete for absorption, researchers have been unable to demonstrate that this is a common problem in human nutrition. At least according to one prominent research group, it appears that our bodies are able to compensate for this issue by increasing iron absorption accordingly. At this time, it does not appear that you need to be careful to eat iron-rich foods away from foods rich in other minerals to enhance or optimize absorption.

Many food constituents can inhibit iron absorption by binding it in the gastrointestinal tract. Prominent examples include phytic acid found in many whole grains and some of the polyphenols found in black tea. In general, consumption of foods like whole grains and black tea does not appear to cause iron-related problems for healthy persons who are not at special medical risk for iron deficiency. But in certain medical situations—for example, iron deficiency anemia or iron storage disease—these interactions might have a significant impact and foods with iron-binding components might need to be avoided We encourage you to consult with your healthcare provider if you have any medical concerns in this regard.

Risk of dietary Toxicity

For most healthy persons, the checks and balances on iron absorption and excretion appear to keep our body stores in a fairly narrow range. This is a good thing since too much stored iron can help to foster free radical damage to the liver and other organs.

However, relatively new research studies have pointed to a possible connection between some very common health problems —including obesity, insulin resistance, and metabolic syndrome—and imbalances in iron metabolism. Somewhat paradoxically, these health problems appear to simultaneously result in altered aspects of iron status that reflect iron deficiency, and other altered aspects that reflect iron excess. Dysmetabolic iron overload syndrome (DIOS) is the name that has been given to factors related to excess. Based on this recent research, it may make sense for persons diagnosed with the above conditions to consult with their healthcare provider and take a closer look at their iron status for issues related to either deficiency or excess before making a final decision about the place of iron-rich foods in their meal plan.

It's important to point out that DIOS is not the same as hemochromatosis. Hemochromatosis is a genetic predisposition in which excess iron retention and storage can occur. It is also estimated to affect between 1-6% of all persons in the U.S. For persons diagnosed with hemochromatosis, restriction of dietary iron is a key part of medical treatment..This restriction not only includes foods that are naturally rich in iron, but also foods that have been enriched or fortified with iron during processing. It also typically includes avoidance of cast iron cookware.

One additional non-food note about iron supplements: Iron supplements represent one of the most common poisoning risks in children. If you are taking an iron supplement, make sure and keep it out of the reach of children.

Disease Checklist

- Anemia
- Fatigue
- Excessive menstrual flow (menorrhagia)
- Pregnancy / lactation
- Attention deficit hyperactivity disorder

Public Health Recommendations

In 2000, the Institute of Medicine at the National Academy of Sciences established Dietary Reference Intake (DRI) standards for iron. These DRI standards included Adequate Intake (AI) level for infants up to 6 months old and Recommended Dietary Allowances (RDA) for all other age categories. These standards are as follows:

- 0-6 months: 0.27 mg
- 7-12 months: 11 mg
- 1-3 years: 7 mg
- 4-8 years: 10 mg
- 9-13 years, female: 8 mg
- 9-13 years, male: 8 mg

- 14-18 years, female: 15 mg
- 14-18 years, male: 11 mg
- 19-30 years, male: 8 mg
- 31-50 years, male: 8 mg
- 51-70 years, male: 8 mg
- 70+ years, male: 8 mg
- 19-30 years, female: 18 mg
- 31-50 years, female: 18 mg
- 51-70 years, female: 8 mg
- 70+ years, female: 8 mg
- Pregnant women, 14-50 years: 27 mg
- Lactating women, 14-18 years: 27 mg
- Lactating women, 19-50 years: 9 mg

The Tolerable Upper Intake Limit (UL) for iron is 45 mg per day for all adults. Given that even the most iron-rich foods have less than 5 mg per serving, it would be very difficult to exceed this regularly through diet alone.

There is also a Daily Value (DV) for iron of 18 mg. This is the standard you'll see reported on food labels, and it is also the standard we adopted at the World's Healthiest Foods as our recommended daily amount.

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The World's Healthiest Foods

World's Healthiest Foods rich in magnesium		
Food	Cals	DRI/DV
Pumpkin Seeds	180	48%
Spinach	41	39%
Swiss Chard	35	38%
Soybeans	298	37%
Sesame Seeds	206	32%
Quinoa	222	30%
Black Beans	227	30%
Cashews	221	29%
Sunflower Seeds	204	28%
Navy Beans	255	24%

Basic Description

Magnesium is a key mineral in human metabolism, and found in small to medium amounts in many of the World's Healthiest Foods. Vegetables (especially green leafy ones), nuts and seeds, and legumes are your best WHFoods sources for magnesium. We like to think of magnesium as the best supporting actor of the mineral kingdom. Like supporting actors in movies, magnesium doesn't get the notoriety of other nutrients like calcium or sodium, but it quietly plays every bit as important a role in human health. In fact, magnesium is necessary for more than 300 chemical reactions in the human body.

While magnesium is present in nutritionally important quantities in many of the foods featured on our site, average American diets frequently fail to contain an adequate supply of magnesium. In fact, adults average only 66% of the Daily Value (DV) for magnesium from their food intake (even though they get another 8% from supplements). This average intake level leaves U.S. adults about 100-125 milligrams short in the magnesium department. A likely reason for this deficient magnesium intake is the tendency of the average U.S. diet to focus predominantly on heavily processed convenience foods at the expense of the green leafy vegetables, nuts and seeds, and legumes that are among our best food sources of the mineral. Increasingly, researchers are becoming aware of a link between poor magnesium nutrition and risks of several important chronic conditions.

Role in Health Support

Creates and Maintains Bone Integrity

About 50 to 60% of a person's magnesium is stored in the bone, and as such, it plays a key role in bone metabolism. Researchers have found that even a mild ongoing magnesium deficiency can lead to a significant amount of bone loss.

Part of the way that this occurs is that when magnesium intake goes too low, levels of parathyroid hormone go down. This leads to a reduced absorption of calcium in the intestines, as well as increased loss of calcium and magnesium in the urine.

A link between adequate magnesium intake and improvements in bone mineral density has been established throughout the life cycle from adolescents all the way to elderly men and women. Researchers have also been able to induce osteoporosis in animal studies through low-magnesium diets—diets that would be similar (at least with respect to %DV intake) to the routine low-grade magnesium-deficient diets humans commonly eat.

We do not know yet whether dietary magnesium has the same level of relative importance as vitamin D or calcium in the maintenance of bone. But the existing research, together with the frequency of magnesium-deficient diets, suggests that low magnesium may be an underappreciated contributor to bone loss.

Enables Energy Production

One critical task performed by our cells is energy production. This task is a complicated one and involves dozens of chemical reactions, all intimately related and flowing in a very special sequence. Unless these chemical reactions can take place in the exact needed order, we don't get the energy production that we need from our cells. Within this energy production sequence,

magnesium plays an important role. Many of the chemical reactions cannot take place unless magnesium is present as "co-factor" for the enzymes that allow energy production to occur. Enzymes are protein molecules that make it easier for chemical reactions to occur throughout the body, including chemical reactions related to energy production. Co-factors are nutrients that must be coupled together with enzymes in order for those enzymes to function.

Based on magnesium's role in energy production within our cells, low levels can be one of the potential contributory factors causing fatigue. Because magnesium deficiency is hard to test via blood work or equivalent laboratory testing, it is not clear what percentage fatigue symptoms are caused or contributed to by magnesium. However, if you look at changes in fatigue symptoms from studies in which participants were given magnesium supplements at levels at least as high as the Recommended Dietary Allowance (RDA) and you couple these study results with information we already know about low intake of magnesium by the average U.S. adult you can draw a conclusion that low dietary intake of magnesium increases our risk of fatigue.

Maintains Nervous System Balance

Receptors are special molecules along our cell membranes that help chemical messages enter and leave our cells. All of the cells in our body have membrane receptors. Among the best studied are receptors found along the membranes of our brain cells. One of these brain cell receptors is referred to as the NMDA receptor. (NMDA stands for N-methyl-d-aspartate.) The NMDA receptor is noted for being the site where some anesthetics and recreational drugs affect our brain function.

Magnesium plays a key role in the activity of our NMDA receptors. Research studies have shown that when magnesium in our diet is low, we have increased risk of depression, and this increased risk is likely related to problems with our NMDA receptors. A long history of published evidence demonstrating that treatment with magnesium can have anti-depressant effect—this was first published in 1921—suggests that low magnesium can actually *cause* depression.

Enhances Control of Inflammation

A diet low in magnesium has been linked to unwanted increases in the inflammatory process. While some amount of inflammation is necessary to support normal immune function and tissue repair after injury, chronic and low-grade inflammation has increasingly been tied to increased risk of heart disease, obesity, and diabetes.

Restoring magnesium levels to recommended intakes has led to normalization of inflammation in clinical trial settings. For example, one large clinical trial found that a Nordic diet strategy—a diet rich in fish, whole grains, and vegetables as sources of magnesium—led to a suppression of the important inflammatory trigger interleukin-1.

Enhances Control of Blood Sugar

Magnesium is a co-factor for over 100 enzymes involved in the control of blood sugar and glucose metabolism. As such, low magnesium status would be expected to have wide-ranging adverse effects on blood sugar control. Researchers have been able to demonstrate both worsening blood sugar control in individuals with low magnesium status and improvements in blood sugar when these low levels begin to normalize. We address this subject in more detail in the section entitled "Other Circumstances That Might Contribute to Deficiency" section.

Summary of Food Sources

While there are few food sources that are strikingly high in magnesium content, a large number of foods contain relevant amounts of this important mineral. In fact, almost half of our World's Healthiest Foods are rated as good, very good, or excellent sources of magnesium. Only three of our WHFoods qualify as an excellent source of magnesium—spinach, Swiss chard, and beet greens. Joining them as very good sources are three additional foods (pumpkin seeds, turnip greens, and summer squash).

Our top 20 WHFoods for magnesium also include numerous legumes, nuts, and seeds. Top legumes for magnesium are navy beans, tempeh (fermented soybeans), pinto beans, lima beans, and kidney beans. The top magnesium-rich nuts and seeds are pumpkin seeds, sesame seeds, sunflower seeds, cashews, and almonds. Among our grains, barley, buckwheat, brown rice, quinoa, and millet also rank in our top 25 magnesium foods. Although a few fruits are ranked as good sources of magnesium, you typically wouldn't turn to fruits for your magnesium, nor to dairy products nor meats.

Within the legume category, we'd like to mention one special soybean-based product that can be significantly higher in magnesium. When soybeans are made into tofu, one specific form of tofu—usually called "nigari tofu" or "tofu prepared from

nigari flakes"—typically contains higher amounts of magnesium that other forms of tofu. That's because magnesium chloride is usually used as a coagulant to curdle the soy milk in this form of tofu.

Drinking water can be surprisingly rich in magnesium, but the magnesium content of water varies dramatically. Generally speaking, water that is allowed to percolate through magnesium-rich soil and rock can pick up a large amount of magnesium. We've seen bottled mineral waters, for example, that provide over 100 milligrams of magnesium per liter. That level means 25% of the Daily Value (DV) in one liter bottle of water. We've also seen municipal water supplies in the U.S. that provide nearly 50 milligrams of magnesium per liter. However, we've also seen reports on municipal water supplies in the U.S. that contain no magnesium whatsoever. If you are drinking tap water from your local water supply, it will typically be your local water district or your local utility district that is charged with monitoring your drinking water quality, including its magnesium content. They'll be able to provide you with actual numbers. Usually these numbers will be reported in terms of parts per million or ppm. (So that know how to convert the numbers, here are two examples: If your local drinking water contains 9 ppm of magnesium, that amount is the same as 9 milligrams per liter while if it contains 90 ppm, that amount is the same as 90 milligrams per liter.)

Introduction to Nutrient Rating System Chart

In order to better help you identify foods that feature a high concentration of nutrients for the calories they contain, we created a Food Rating System. This system allows us to highlight the foods that are especially rich in particular nutrients. The following chart shows the World's Healthiest Foods that are either an excellent, very good, or good source of magnesium. Next to each food name, you'll find the serving size we used to calculate the food's nutrient composition, the calories contained in the serving, the amount of magnesium contained in one serving size of the food, the percent Daily Value (DV%) that this amount represents, the nutrient density that we calculated for this food and nutrient, and the rating we established in our rating system. For most of our nutrient ratings, we adopted the government standards for food labeling that are found in the U.S. Food and Drug Administration's "Reference Values for Nutrition Labeling." Read more background information and details of our rating system.

World's Healthiest Foods ranked as quality sources of magnesium						
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Spinach	1 cup	41.4	156.60	39	17.0	excellent
Swiss Chard	1 cup	35.0	150.50	38	19.4	excellent
Beet Greens	1 cup	38.9	97.92	24	11.3	excellent
Pumpkin Seeds	0.25 cup	180.3	190.92	48	4.8	very good
Summer Squash	1 cup	36.0	43.20	11	5.4	very good
Turnip Greens	1 cup	28.8	31.68	8	4.9	very good
Soybeans	1 cup	297.6	147.92	37	2.2	good
Sesame Seeds	0.25 cup	206.3	126.36	32	2.8	good
Black Beans	1 cup	227.0	120.40	30	2.4	good
Quinoa	0.75 cup	222.0	118.40	30	2.4	good
Cashews	0.25 cup	221.2	116.80	29	2.4	good
Sunflower Seeds	0.25 cup	204.4	113.75	28	2.5	good
Navy Beans	1 cup	254.8	96.46	24	1.7	good
Tempeh	4 oz	222.3	87.32	22	1.8	good
Buckwheat	1 cup	154.6	85.68	21	2.5	good
Pinto Beans	1 cup	244.5	85.50	21	1.6	good
Brown Rice	1 cup	216.4	83.85	21	1.7	good
Barley	0.33 cup	217.1	81.57	20	1.7	good
Lima Beans	1 cup	216.2	80.84	20	1.7	good
Millet	1 cup	207.1	76.56	19	1.7	good
Kidney Beans	1 cup	224.8	74.34	19	1.5	good
Oats	0.25 cup	151.7	69.03	17	2.0	good
Tofu	4 oz	164.4	65.77	16	1.8	good
Almonds	0.25 cup	132.2	61.64	15	2.1	good
Rye	0.33 cup	188.5	61.35	15	1.5	good

Wheat	1 cup	151.1	58.24	15	1.7	good
Papaya	1 medium	118.7	57.96	14	2.2	good
Flaxseeds	2 TBS	74.8	54.88	14	3.3	good
Green Peas	1 cup	115.7	53.72	13	2.1	good
Tuna	4 oz	147.4	47.63	12	1.5	good
Scallops	4 oz	125.9	41.96	10	1.5	good
Collard Greens	1 cup	62.7	39.90	10	2.9	good
Beets	1 cup	74.8	39.10	10	2.4	good
Broccoli	1 cup	54.6	32.76	8	2.7	good
Brussels Sprouts	1 cup	56.2	31.20	8	2.5	good
Raspberries	1 cup	64.0	27.06	7	1.9	good
Winter Squash	1 cup	75.8	26.65	7	1.6	good
Cabbage	1 cup	43.5	25.50	6	2.6	good
Asparagus	1 cup	39.6	25.20	6	2.9	good
Kale	1 cup	36.4	23.40	6	2.9	good
Green Beans	1 cup	43.8	22.50	6	2.3	good
Tomatoes	1 cup	32.4	19.80	5	2.8	good
Cantaloupe	1 cup	54.4	19.20	5	1.6	good
Strawberries	1 cup	46.1	18.72	5	1.8	good
Bok Choy	1 cup	20.4	18.70	5	4.1	good
Mustard Greens	1 cup	36.4	18.20	5	2.2	good
Cumin	2 tsp	15.8	15.37	4	4.4	good
Parsley	0.50 cup	10.9	15.20	4	6.3	good
Watermelon	1 cup	45.6	15.20	4	1.5	good
Mustard Seeds	2 tsp	20.3	14.80	4	3.3	good
Fennel	1 cup	27.0	14.79	4	2.5	good
Leeks	1 cup	32.2	14.56	4	2.0	good
Basil	0.50 cup	4.9	13.57	3	12.5	good
Cucumber	1 cup	15.6	13.52	3	3.9	good
Romaine Lettuce	2 cups	16.0	13.16	3	3.7	good
Cauliflower	1 cup	28.5	11.16	3	1.8	good
Celery	1 cup	16.2	11.11	3	3.1	good
Bell Peppers	1 cup	28.5	11.04	3	1.7	good
Cloves	2 tsp	11.5	10.88	3	4.3	good

World's Healthiest Foods Rating	Rule
excellent	DRI/DV>=75% OR Density>=7.6 AND DRI/DV>=10%
very good	DRI/DV>=50% OR Density>=3.4 AND DRI/DV>=5%
good	DRI/DV>=25% OR Density>=1.5 AND DRI/DV>=2.5%

Impact of Cooking, Storage and Processing

Magnesium—like all minerals—is an element that has always existed on the earth, in foods, and in our body. In this context, some people look at magnesium (and other minerals) as not only being forever unchanged in the history of the planet but also as being unchanging in its very nature as an element. From a food perspective, however, we think it makes more sense to treat magnesium as a nutrient that can undergo change, because magnesium is not usually found in food in its simple elemental form. For example, in drinking water, magnesium is often found in the form of dissolved salts like magnesium chloride or magnesium sulfate. In plant foods, it often occurs as part of the chlorophyll molecule. (Chlorophyll is a green pigment that not only gives so many plants their color but also allows them to turn sunlight into energy.) These different food forms of magnesium can be changed through cooking.

We reviewed several recent studies in which fresh vegetables or legumes were boiled for relatively short periods of time and then analyzed for changes in magnesium content. In one study, French beans, broad beans, and peas were boiled for eight to twelve minutes, and in a second study, spinach and kale were boiled for two to three minutes. Especially when a vegetable is boiled very briefly prior to freezing, this process is often referred to as "blanching." (The spinach and kale referred to above were described as being "blanched" by the researchers conducting the study.) In the case of French beans, spinach, and kale, researchers found between 20-30% magnesium loss due to boiling, and in the case of broad beans and peas, a loss of 2-10%.

You'll find specific tips on food storage in the "How to Select and Store" sections of our individual food profiles. Since legumes, nuts, and seeds are among our best WHFoods sources for magnesium and since these foods can usually be stored for relatively long periods of time, stability problems with magnesium in stored foods are not typically a concern.

While not appearing in our top WHFoods sources for magnesium, whole grains can still be a good source of this mineral. However, much of their magnesium content can be lost through the refining process. For example, whole wheat flour contains about six times as much magnesium by weight compared to white flour. (By the term "white flour," we are referring to whole wheat that has undergone 60% extraction during milling such that 40% of the original grain—mostly the bran and germ portion—has been removed during milling. Unlike some of the vitamins and minerals that are reduced or totally lost during grain processing (at least 19 nutrients undergo processing loss), magnesium is not added back into processed grain flours to "enrich" the final grain products. The Food and Drug Administration (FDA) has only set standards of enrichment for four nutrients lost during grain processing (vitamins B1, B2, B3 and the mineral iron). Even though magnesium is lost during grain processing, no standard has been set by the FDA for magnesium enrichment of grain products. For this reason, if you do decide to incorporate grains into your meal plan as a possible magnesium source, whole grain products are the best way for you to get as much magnesium as possible from your grains.

Risk of Dietary Deficiency

In the U.S., the risk of dietary deficiency of magnesium is very high. In fact, the average U.S. adult falls well short of the 400 mg per day Daily Value (DV) and consumes only 266 milligrams of magnesium from food. Since some foods are fortified with added magnesium, the average U.S. adult gets an additional 10 milligrams of magnesium from fortification. That brings the food total to 276 milligrams, with another 34 milligrams (on average) from dietary supplements, for a grand total of 310 milligrams —still only three-quarters of the DV.

Among the top ten food contributors to America's total magnesium intake are items like coffee, beer, and French fries. It's not that these foods are good magnesium sources, just that we eat (or drink) a lot of them.

Diets rich in green leafy vegetables, legumes, nuts, and seeds —and to a lesser extent, whole grains —would be the best way for you to limit your risk of having magnesium deficiency. Two servings from each of these categories daily could put you at or above the DV for magnesium.

Here's an example of some everyday food choices that would provide you with the DV for magnesium:

- 2 ounces of cashew nuts and 2 cups of boiled spinach
- 2 ounces pumpkin seeds, 2 ounces cashews, and 2 ounces of almonds

Other Circumstances that Might Contribute to Deficiency

One of the most important contributors to deficiency of magnesium is high blood sugar, including diabetes. Obesity is related to magnesium deficiency, too, but this relationship is currently thought to be the result of blood sugar elevations.

Surprisingly, it looks like the relationship between low magnesium diets and high blood sugar goes in both directions—in other words, a diet low in magnesium-rich foods tends to lead to poor blood sugar control. This poor blood sugar control in turn exacerbates the low magnesium level. To break up this unwanted sequences of events , a group of nutritionists affiliated with Tufts University suggested that older adults should be counseled about the importance of eating green vegetables, legumes, and whole grains as sources of magnesium.

The rate of magnesium deficiency goes up with age, with average intakes in the elderly dropping by 25% or more from middle-aged adults. African-Americans have much higher rates of magnesium deficiency than Caucasians.

Older patients with heart failure and chronic obstructive pulmonary disease (COPD) also have been found to have high risks of magnesium deficiency. In both conditions, improving magnesium levels has been found to lead to health benefits in smaller research trials.

Medications can deplete magnesium levels as well. In particular, people taking diuretics should talk to their doctor about the importance of ensuring good supply of dietary magnesium.

Relationship with Other Nutrients

Magnesium, calcium, and phosphorus have a complex relationship with respect to absorption in the intestine. How much of each of these nutrients goes into the blood stream versus being lost in the stool is variable by relative amount, hormonal balance, and even time of day.

In general, more magnesium tends to reduce phosphorus absorption. This is not necessarily a problem, since the average U.S. diet does not correspond with phosphorus deficiency.

The relationship between calcium and magnesium has been of longstanding interest in research. Scientists have long been aware that these two minerals belong to the same family of elements (alkali earth metals), take on the same electrical charge (2+), and have a predictable ratio in different types of soil. However, only in recent studies have we learned more about specific details about calcium and magnesium in terms of dietary intake and absorption rate. It turns out that absorption of magnesium from our intestine depends not only on the amount of magnesium that is present but also on the amount of calcium that is present, because the cells lining our intestine have a single spot (called the CaSR receptor) for absorbing these minerals. In practical terms, these circumstances suggest that our diet needs to be balanced in terms of magnesium, calcium, and the ratio of these two minerals.

At the World's Healthiest Foods, we recommend 400 milligrams of daily magnesium (the Daily Value amount) and 1,000 milligrams of daily calcium (the Dietary Reference Intake level for women 19-50 years of age). These recommendations would combine to form a calcium:magnesium ratio of 2.5:1. Since the average U.S. adult only averages 266 milligrams of magnesium intake from food, as compared with approximately 1,000 milligrams of calcium from food (about 1,150 milligrams for men 20 years and older and about 900 milligrams for women 20 years and older), an average calcium:magnesium ratio in the U.S. diet would be approximately 3.75:1, or 50% greater than a ratio based on our WHFoods recommendations. Since many people in the U.S. (especially women) don't currently consume enough calcium in their diet, it would be a great mistake for most people to try and balance their calcium:magnesium ratio by cutting back on calcium-rich foods. So in order to achieve a lower ratio, increased emphasis on magnesium-rich foods seems like the best approach.

Risk of dietary Toxicity

The risk of dietary toxicity from magnesium for healthy adults is very low. Too much magnesium from supplements has been linked to loose stools, but this is unlikely to occur from foods alone. Reflecting this low risk, the Institute of Medicine (IOM) at the National Academy of Sciences has established no upper limit for dietary intake of magnesium.

People with renal failure, especially if they are on dialysis, will likely need to work with a trained nutrition specialist to obtain safe recommendations about magnesium intake. The recommendations on this site are not appropriate for patients on dialysis.

Disease Checklist

- Coronary artery disease
- Arrhythmia
- Mitral valve prolapse
- Congestive heart failure
- Hypertension
- Diabetes
- Osteoporosis
- Muscle cramping
- Chronic fatigue
- Depression
- Anxiety
- Asthma
- COPD / Emphysema
- Fatty liver disease (NASH)

Public Health Recommendations

In 1997, the National Academy of Sciences established a set of Dietary Reference Intakes (DRIs) for magnesium that included age and gender specific Recommended Dietary Allowances (RDAs) for magnesium. Note that the recommendation for infants from 0-12 months of age is an Adequate Intake (AI) recommendation rather than an RDA. The AIs and RDAs are as follows:

- 0-6 months: 30 mg
- 7-12 months: 75 mg
- 1-3 years: 80 mg
- 9-13 years: 240 mg
- 14-18 years, female: 360 mg
- 14-18 years, male: 360 mg
- 19-30 years, female: 310 mg
- 19-30 years, male: 400 mg
- 31+ years, female: 320 mg
- 31+ years, male: 400mg
- Pregnant women, 14-18 years: 400 mg
- Pregnant women, 19-30 years: 350 mg
- Pregnant women, 31-50 years: 360 mg
- Lactating women, 14-18 years: 360 mg
- Lactating women, 19-30 years: 310 mg
- Lactating women, 31-30 years: 320 mg

The U.S. Food and Drug Administration (FDA) set 400 milligrams of magnesium as its recommended daily amount, or Daily Value (DV). DVs are the standards that you see on the Nutrition Facts Panel for a packaged food. We used this magnesium DV as our WHFoods recommended daily amount.

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The World's Healthiest Foods

World's Healthiest Foods rich in manganese		
Food	Cals	DRI/DV
Cloves	12	127%
Oats	152	96%
Brown Rice	216	88%
Garbanzo Beans	269	85%
Spinach	41	84%
Pineapple	83	77%
Pumpkin Seeds	180	74%
Tempeh	222	73%
Rye	189	72%
Soybeans	298	71%

Basic Description

When you think of dietary minerals, you probably think first of calcium or iron. If you spend a lot of time thinking about nutrition, you may also think about zinc or magnesium. But there are a whole group of trace minerals, which are not generally as well known, that we derive from our diets in very small amounts that are just as critical to healthy lifestyles.

One of these is manganese. In the 1930s, researchers discovered that our bodies require small amounts of dietary manganese each day. Since then, it has been determined that each adult has about 15-20 mg of manganese stored in his or her body. Needless to say, this isn't very much, and in fact some people occasionally eat this much dietary manganese in a single day.

Largely plant-based diets—like those we promote at the World's Healthiest Foods—tend to be rich sources of manganese. Of the World's Healthiest Foods, we currently rate 21 as excellent sources of manganese. We also have 38 very good sources and 26 good sources. Added together, these foods represent 85% of all WHFoods! This large variety gives you many options for obtaining the manganese you need.

Role in Health Support

Bone Production

We know from animal studies that very low intakes of manganese are associated with poor bone formation. This phenomenon is thought to be due to altered formation of the protein matrix that keeps minerals like calcium in place.

Whether low or marginal manganese intake is a common contributor to bone loss is not known currently. Given that U.S. diets tend to be well above total manganese needs, it appears unlikely that increasing manganese intakes is necessary or helpful in prevention or treatment of osteoporosis.

Skin integrity

Manganese is a required co-factor for an enzyme called *prolidase*, which is in turn necessary to make collagen as a structural component of skin. This role of manganese in collagen production makes this mineral important for everyday skin health. In addition to its collagen production role, manganese also functions as an antioxidant in skins cells and other cell types. It helps protect skin against oxygen-related damage and also against damage from ultraviolet (UV) light. In at least one human study, participants on manganese-deficient diets over a period of weeks developed skin rashes that the researchers associated with too little dietary manganese. After the participants resumed consumption of a manganese-rich diet, these rashes disappeared. There can be an extremely wide variety of reasons for development of skin rashes, and so this study did not mean to suggest that whenever a person has a skin rash, there may very likely be some problem with manganese intake. But this study did point out that manganese deficiency can sometimes play a role in skin problems, including rashes.

Blood Sugar Control

Manganese is needed to help multiple enzymes in a process called gluconeogenesis. Gluconeogenesis is the scientific term for conversion of substances like amino acids or organic acids into sugar. Our cells routinely engage in this process, and some of the enzymes involved (like PEPCK, or phosphoenolpyruvate carboxykinase) require manganese to function properly.

Scientists aren't sure about the relationship between diseases involving poor blood sugar control and dietary intake of manganese. In animal studies, manganese-depleted diets can lead to high blood sugars similar to those seen in diabetics. Whether this is true in humans has not been determined.

Either way, we suspect that manganese deficiency is probably not a common contributor to human diabetes. People with diabetes do not consistently have lower manganese intake than people without diabetes. Also, supplementation with large doses of manganese—doses at the top end of what would be seen with plant-based diets—do not appear to improve blood sugar control in diabetes. However, even though manganese deficiency may not directly increase risk of diseases related to blood sugar control (like diabetes), it is still likely to play a very helpful role in everyday blood sugar control.

Protection Against Free Radical Damage

As noted above, manganese is a co-factor for an enzyme called manganese superoxide dismutase (MnSOD), which is a potent antioxidant associated with protection against free radical damage. Diets low in manganese have been linked to conditions marked by increased free radical damage to cells and tissue,,including skin problems and asthma.

Summary of Food Sources

As noted above, the World's Healthiest Foods contain a large number of excellent and very good sources of manganese. These represent a variety of food groups, including whole grains, legumes, vegetables, and fruits.

Unlike most minerals, we see foods on the list that contain close to or the entire Daily Value (DV) for manganese in a single serving. One quarter cup of dried oats, for example, provides 96% of the DV for manganese.

It's worth pointing out that among our 85 WHFoods that rank as excellent, very good, or good sources of manganese, none are animal foods. That's because animal foods are typically low in manganese, and provide 5% or less of the DV.

Introduction to Nutrient Rating System Chart

In order to better help you identify foods that feature a high concentration of nutrients for the calories they contain, we created a Food Rating System. This system allows us to highlight the foods that are especially rich in particular nutrients. The following chart shows the World's Healthiest Foods that are either an excellent, very good, or good source of manganese. Next to each food name, you'll find the serving size we used to calculate the food's nutrient composition, the calories contained in the serving, the amount of manganese contained in one serving size of the food, the percent Daily Value (DV%) that this amount represents, the nutrient density that we calculated for this food and nutrient, and the rating we established in our rating system. For most of our nutrient ratings, we adopted the government standards for food labeling that are found in the U.S. Food and Drug Administration's "Reference Values for Nutrition Labeling." Read more background information and details of our rating system.

World's Healthiest Foods ranked as quality sources of manganese						
Food	Serving Size	Cals	Amount (mg)	DRI/DV (%)	Nutrient Density	World's Healthiest Foods Rating
Cloves	2 tsp	11.5	2.53	127	197.8	excellent
Oats	0.25 cup	151.7	1.92	96	11.4	excellent
Brown Rice	1 cup	216.4	1.76	88	7.3	excellent
Garbanzo Beans	1 cup	269.0	1.69	85	5.7	excellent
Spinach	1 cup	41.4	1.68	84	36.5	excellent
Pineapple	1 cup	82.5	1.53	77	16.7	excellent
Collard Greens	1 cup	62.7	0.97	49	13.9	excellent
Cinnamon	2 tsp	12.8	0.91	46	63.8	excellent
Raspberries	1 cup	64.0	0.82	41	11.5	excellent
Black Pepper	2 tsp	14.6	0.74	37	45.7	excellent

Beet Greens	1 cup	38.9	0.74	37	17.1	excellent
Swiss Chard	1 cup	35.0	0.58	29	14.9	excellent
Strawberries	1 cup	46.1	0.56	28	10.9	excellent
Kale	1 cup	36.4	0.54	27	13.4	excellent
Turnip Greens	1 cup	28.8	0.49	25	15.3	excellent
Mustard Greens	1 cup	36.4	0.38	19	9.4	excellent
Summer Squash	1 cup	36.0	0.38	19	9.5	excellent
Turmeric	2 tsp	15.6	0.34	17	19.6	excellent
Sea Vegetables	1 TBS	10.8	0.31	16	25.7	excellent
Garlic	6 cloves	26.8	0.30	15	10.1	excellent
Basil	0.50 cup	4.9	0.24	12	44.3	excellent
Bok Choy	1 cup	20.4	0.24	12	10.6	excellent
Pumpkin Seeds	0.25 cup	180.3	1.47	74	7.3	very good
Tempeh	4 oz	222.3	1.46	73	5.9	very good
Rye	0.33 cup	188.5	1.44	72	6.9	very good
Soybeans	1 cup	297.6	1.42	71	4.3	very good
Tofu	4 oz	164.4	1.34	67	7.3	very good
Barley	0.33 cup	217.1	1.19	60	4.9	very good
Quinoa	0.75 cup	222.0	1.17	59	4.7	very good
Wheat	1 cup	151.1	1.11	56	6.6	very good
Walnuts	0.25 cup	196.2	1.02	51	4.7	very good
Sweet Potato	1 cup	180.0	0.99	50	5.0	very good
Lentils	1 cup	229.7	0.98	49	3.8	very good
Lima Beans	1 cup	216.2	0.97	49	4.0	very good
Navy Beans	1 cup	254.8	0.96	48	3.4	very good
Sesame Seeds	0.25 cup	206.3	0.89	45	3.9	very good
Green Peas	1 cup	115.7	0.72	36	5.6	very good
Buckwheat	1 cup	154.6	0.68	34	4.0	very good
Beets	1 cup	74.8	0.55	28	6.6	very good
Almonds	0.25 cup	132.2	0.53	27	3.6	very good
Blueberries	1 cup	84.4	0.50	25	5.3	very good
Winter Squash	1 cup	75.8	0.38	19	4.5	very good
Cranberries	1 cup	46.0	0.36	18	7.0	very good
Green Beans	1 cup	43.8	0.36	18	7.4	very good
Brussels Sprouts	1 cup	56.2	0.35	18	5.6	very good
Flaxseeds	2 TBS	74.8	0.35	18	4.2	very good
Cabbage	1 cup	43.5	0.33	17	6.8	very good
Broccoli	1 cup	54.6	0.30	15	4.9	very good
Asparagus	1 cup	39.6	0.28	14	6.4	very good
Leeks	1 cup	32.2	0.26	13	7.3	very good
Tomatoes	1 cup	32.4	0.21	11	5.8	very good
Fennel	1 cup	27.0	0.17	9	5.7	very good
Cauliflower	1 cup	28.5	0.16	8	5.0	very good
Romaine Lettuce	2 cups	16.0	0.15	8	8.4	very good
Miso	1 TBS	34.2	0.15	8	3.9	very good
Cumin	2 tsp	15.8	0.14	7	8.0	very good
Mushrooms, Crimini	1 cup	15.8	0.10	5	5.7	very good
Oregano	2 tsp	5.3	0.10	5	17.0	very good
Mustard Seeds	2 tsp	20.3	0.10	5	4.4	very good
Celery	1 cup	16.2	0.10	5	5.6	very good
Dried Peas	1 cup	231.3	0.78	39	3.0	good
Pinto Beans	1 cup	244.5	0.77	39	2.8	good

Black Beans	1 cup	227.0	0.76	38	3.0	good
Kidney Beans	1 cup	224.8	0.76	38	3.0	good
Peanuts	0.25 cup	206.9	0.71	36	3.1	good
Sunflower Seeds	0.25 cup	204.4	0.68	34	3.0	good
Cashews	0.25 cup	221.2	0.66	33	2.7	good
Millet	1 cup	207.1	0.47	24	2.0	good
Potatoes	1 cup	160.9	0.38	19	2.1	good
Banana	1 medium	105.0	0.32	16	2.7	good
Onions	1 cup	92.4	0.32	16	3.1	good
Carrots	1 cup	50.0	0.17	9	3.1	good
Mushrooms, Shiitake	0.50 cup	40.6	0.15	8	3.3	good
Corn	1 each	73.9	0.13	7	1.6	good
Eggplant	1 cup	34.6	0.11	6	2.9	good
Bell Peppers	1 cup	28.5	0.10	5	3.2	good
Peppermint	2 TBS	5.3	0.09	5	15.2	good
Soy Sauce	1 TBS	10.8	0.09	5	7.5	good
Chili Peppers	2 tsp	15.2	0.09	5	5.3	good
Cucumber	1 cup	15.6	0.08	4	4.6	good
Thyme	2 TBS	4.8	0.08	4	14.8	good
Kiwifruit	1 2 inches	42.1	0.07	4	1.5	good
Figs	1 medium	37.0	0.06	3	1.5	good
Dill	0.50 cup	1.9	0.06	3	28.3	good
Parsley	0.50 cup	10.9	0.05	3	4.1	good

World's Healthiest Foods Rating	Rule
excellent	DRI/DV>=75% OR Density>=7.6 AND DRI/DV>=10%
very good	DRI/DV>=50% OR Density>=3.4 AND DRI/DV>=5%
good	DRI/DV>=25% OR Density>=1.5 AND DRI/DV>=2.5%

Impact of Cooking, Storage and Processing

Manganese content of foods tends to be stable throughout their shelf life, provided that they are stored properly for the recommended period of time. If you would like to learn more about how to best keep foods, each of our World's Healthiest Food profiles contains a section on How to Select and Store for best quality.

In legumes, cooking does not appear to lead to much or any loss of manganese. With vegetables, you may expect a little more loss of manganese with cooking. Still, you'll be able to minimize this loss by reducing cooking time and contact with cooking water. For instance, the manganese loss after cooking spinach with a brief boil time was less than 10%. Our food profiles always provide you with precise recommendations for cooking times and cooking methods that will help you preserve nutrients, including manganese.

Risk of Dietary Deficiency

Typical non-vegetarian diets contain about 2 to 7 mg of manganese daily. Vegetarians tend to have more manganese and can approach 10 or more mg daily. As reflected in the Food Source section,both dietary patterns should typically be able to meet or surpass the 2 mg per day Daily Value (DV) recommendation.

lt would be almost impossible to eat a diet that was based on the World's Healthiest Foods and not get plenty of manganese, especially if that diet contained plenty of our World's Healthiest plant foods. Nearly all of our listed foods contain at least some of this mineral, and 85 of our plant foods rate as good, very good, or excellent sources of manganese.

Other Circumstances that Might Contribute to Deficiency

Since we are not aware of any studies showing widespread manganese deficiency among any population groups within the U.S., and because dietary deficiency of manganese appears to be the foremost cause of manganese deficiency in all countries that have been studied by researchers, we have not been able to identify circumstances outside of your dietary intake that might put you a greater risk for manganese deficiency. Of course, like all nutrient deficiencies, manganese deficiency can be caused by unusual medical problems. For example, we've seen studies showing a connection between bowel surgeries and manganese deficiency. However, when people have unusual medical problems, they often develop multiple nutrient deficiencies, and these kinds of problems require the involvement of the individual's healthcare team.

Relationship with Other Nutrients

Animal studies suggest that iron deficiency can increase the absorption of dietary manganese. The converse—that high levels of iron can interfere with absorption of manganese—also appears to be true. It's not clear, however, exactly what these animal studies mean for humans, except to suggest that we typically want to avoid extremely high or extremely low intake of either mineral. We have seen some human studies on manganese in children who are iron deficient, and in some of these studies, these children have shown elevated levels of manganese in their blood that may be of possible concern. These studies are further evidence of a special relationship between manganese and iron. In a practical sense, the bottom line here for us is simple: when talking to your healthcare provider about possible concerns with either mineral, it makes sense to ask questions about the other mineral as well. (Please see our profile for iron for more information on this nutrient.)

Calcium and magnesium also can compete with manganese for absorption. Although this has not been reported as a cause of manganese deficiency in humans, it is possible that high calcium and/or magnesium diets may slightly impair manganese nutrition. However, from a practical standpoint, many diets that are high in calcium and/or magnesium—especially if these minerals are primarily obtained from plant foods—are simultaneously high in manganese, making the risk of manganese deficiency relatively low.

Risk of dietary Toxicity

In 2001, The National Academy of Sciences (NAS) established a Tolerable Upper Intake Level (UL) of 11 mg for total daily manganese intake for adults 19 and older. This level was based on the uppermost amount of manganese found in the diet of healthy people.. While we support the establishment of this UL recommendation from the NAS, we would also point out that it was not based on evidence about unwanted health consequences if this dietary level was exceeded. In other words, the NAS did not have evidence about health problems that might occur if dietary intake of manganese routinely exceeded this 11 mg level. The NAS only had evidence that no such problems had been observed in U.S. adults whose average daily manganese intake was as high as 11 mg. So the NAS adopted this 11 mg UL level to err on the conservative side in its public health recommendation.

Dietary manganese levels can be surprisingly high in some populations. In fact, unlike most required dietary minerals, it is not especially difficult to exceed the UL of 11 mg with very reasonable dietary intake. For example, if you eat one serving from each of our Top 10 manganese-rich foods in one day, you will exceed the manganese UL. As described above, we are not aware of any reason to deliberately avoid manganese-rich foods, provided that you consume an overall balanced diet with optimal intake of other minerals and do not have health problems that might compromise your body's handling of these minerals,

Disease Checklist

- Osteoporosis
- Tardive dyskinesia
- Hypothyroidism
- Diabetes
- Dermatitis
- Epilepsy
- Asthma

Public Health Recommendations

In 2001, the National Academy of Sciences published Dietary Reference Intakes (DRIs) for manganese. These DRIs were Adequate Intake levels, or AIs. Here are those recommendations as established by the NAS:

- 0-6 months: 0.003 mg
- 7-12 months: 0.6 mg
- 1-3 years: 1.2 mg
- 4-8 years: 1.5 mg
- 9-13 years, female: 1.6 mg
- 9-13 years, male: 1.9 mg
- 14-18 years, female: 1.6 mg
- 14-18 years, male: 2.2 mg
- 19+ years, female: 1.8 mg
- 19+ years, male: 2.3 mg
- Pregnant women: 2.0 mg
- Lactating women: 2.6 mg

These 2001 DRI guidelines also established a Tolerable Upper Intake Level (UL) of 11 mg for total daily manganese intake. For more information about this UL recommendation, please see our Risk of Dietary Toxicity section.

The Daily Value (DV) for manganese is 2 mg per 2000 calories. This is the recommendation that is used in the food charts below, and it is also the standard that we adopt as our WHFoods standard.

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The World's Healthiest Foods

World's Healthiest Foods rich in molybdenum		
Food	Cals	DRI/DV
Lentils	230	330%
Dried Peas	231	327%
Lima Beans	216	313%
Kidney Beans	225	295%
Soybeans	298	287%
Black Beans	227	287%
Pinto Beans	245	285%
Garbanzo Beans	269	273%
Oats	152	64%
Barley	217	60%

Basic Description

Although perhaps not as well known as other minerals that we profile on our website, molybdenum is a key mineral nutrient found in a variety of WHFoods and known to play important roles in many different body systems.

Our understanding of molybdenum and human health did not begin with research on humans, but on soil, water, and microorganisms. Molybdenum has long been known to play a central role in soil chemistry, and in ocean chemistry as well. Some of the most fundamental components in soil and water chemistry—including basic interactions involving carbon, nitrogen, and sulfur—are significantly impacted by molybdenum and its role in chemical events. Not surprisingly, the molybdenum content of our food is significantly dependent on the soil in which foods are grown and the water supplied during the raising of the plants (or animals).

Like all nutrients, molybdenum needs to be consumed in amounts that fall within a healthy range, and it can be problematic to consume either too much or too little. We have research studies on both ends of this spectrum. On the one hand, there are studies showing healthy intake of molybdenum from molybdenum-rich soils and groundwater to be associated with increased longevity. (Studies involving rice intake in Zhongxiang, China are good examples of research because the growing circumstances for the rice involved molybdenum-rich soil and water.) At the same time, we have studies that show increased toxicity risk when industries release excessive amounts of molybdenum into the environment. (The manufacturing of light bulbs that require tungsten filaments and coils is a good example of an activity that can create potentially toxic levels of molybdenum in the surrounding air, water, and soil.) As a general rule, the general types of food that we eat in the U.S. and the many different environments in which these foods are grown tend to provide us with average amounts of molybdenum above the minimal requirement range yet well below an excessive level.

Role in Health Support

Unfortunately, scientists know more about the role of molybdenum in the environment and in non-human organisms than they do about the role of molybdenum in human health. Still, this mineral has been shown to be required for the activity of at least seven enzymes in our body, and numerous body systems rely on these enzymes for support. The information below is based on our understanding of these molybdenum-requiring enzymes and their rule in everyday health.

Promotion of Optimal Sulfur Balance

Sulfur is an element of surprising importance in our health. It's a unique part of the protein in our food because most foods contain at least small amounts of sulfur amino acids, including taurine, methionine, and cysteine. Sulfur is critical in our ability to detoxify unwanted contaminants, and many contaminants in our food cannot be eliminated from our body without the help of sulfur. This element is also essential in our body's antioxidant protection, and many of our most critical antioxidant molecules—including glutathione—are sulfur-containing. Sulfur also plays a unique role in the structure of our connective tissue, through its incorporation into molecules like glucosamine sulfate and chondroiton sulfate. So as you can see, this mineral is truly "whole body" in its health support role.

The same conclusion could be made about molybdenum as well, based on its required role in the activity of an enzyme called sulfite oxidase (SO). The role of SO is to take one form of sulfur (sulfite) and convert it into another form (sulfate). While this step sounds relatively simple, it is actually critical for keeping sulfur moving around in our body as intended and allowing all of the activities described in the paragraph above to take place. In other words, we suspect a role for molybdenum in support of liver detoxification, antioxidant support, connect tissue development, and other aspects of our health due to the widespread important of sulfur balance throughout our body.

While SO exits in many different organ systems in our body, two especially important places are our liver and brain. In the liver, SO is known to play a key role in support of detoxification. Our liver cells cannot do their job as detoxifiers if there is too much build-up of sulfite and not enough availability of sulfate, and SO helps prevent that problematic situation from occurring. (Within this context of detoxification, it is also important to note that molybdenum is a cofactor for the enzyme *aldehyde oxidase*, which is critical during the first phase of liver cell detoxification, called phase I.)

In the brain, we know that babies born with disruptions in molybdenum metabolism can have SO disruptions as well and can experience severe brain- and nervous system-related problems for this reason. The details here can get confusing, but they center on the role of a molecule called molybdenum cofactor, or Moco. Moco is the compound formed when molybdenum is combined with a molecule called pyranopterin. This molybdenum-containing compound turns out to be the form in which molybdenum helps to activate SO. While it is rare for babies to be born without the ability to make Moco, when this situation does occur, it can result in dramatic problems.

There are no small-scale or large-scale studies on humans to show whether dietary deficiency of molydenum can cause problems in detoxification, antioxidant protection, or brain and nervous system function. At the very least, we would suspect that over long periods of time (measured in years), very low intake of molybdenum would put people at risk of problems involving imbalanced sulfur metabolism. But there are simply no studies in this area. In addition, most of the studies that we have seen estimating dietary intake of molybdenum fall into the range of 80-300 micrograms per day, and with the Dietary Reference Intake (DRI) recommendation of 45 micrograms for adults 19 and older, you can see how evidence about dietary deficiency of this mineral might be difficult to obtain.

Antioxidant Protection

In addition to its role in SO activity, molybdenum is also a cofactor for an enzyme called *xanthine oxidase* (XO). XO is responsible for taking two molecules (called hypoxanthine and xanthine) and helping convert them into uric acid (UA). One context in which you might have heard about XO and UA is the medical condition often referred to as "gout," in which crystals of UA can build up in the joints and case pain. Medications used to help treat this condition often work by blocking the activity of XO. While it is true that too much uric acid can be a bad thing in some individuals, it is equally true that healthy amounts of uric acid are also quite important for all of us. We know, for example, that UA plays a primary role in the total antioxidant capacity of our bloodstream—as important, for example, as vitamins E and C. We also know that UA can play a direct antioxidant role in other part of our body. What we don't know is how these antioxidant functions of UA are related either to diet or to risk of disease. The lack of research in this area makes it impossible for us to say whether dietary deficiency of molybdenum might result in problems with UA formation that are accompanied by increased disease risk. But our knowledge of basic science in this area tells us that molybdenum is likely to contribute to our antioxidant protection by maintaining proper function of XO and balanced production of UA.

Other Potential Roles in Health Support

Because of its known role as a cofactor for the enzyme *aldehyde dehydrogenase* (ADH), molybdenum is likely to play an important role in nervous system metabolism, and particularly metabolism of the nervous system messaging molecules (neurotransmitters) epinephrine, norepinephrine, serotonin, and melatonin. ADH enzyme activity is critical for the breakdown of the neurotransmitters listed above, and the rate of breakdown of these molecules is closely related to their rate of synthesis and availability for nervous system function.

Molybdenum is also known to be required in formation of unique proteins called amidoxime reducing component proteins, or mARC. These proteins play important roles in mitochondrial function. (Mitochondria are energy-producing components in cells that participate in oxygen-based energy production, also called aerobic energy production.) However, this area of study is in its infancy and we are quite a way from practical conclusions involving dietary molybdenum intake and this aspect of mitochondrial function.

Summary of Food Sources

About 20% of our WHFoods qualify as ranked sources of molybdenum. While this number is relatively small compared to many of the nutrients that we profile on our website, we suspect that the actual number of molybdenum-containing foods is much higher. However, food databases like the U.S. Department of Agriculture's National Nutrient Database for Standard Reference do not even include molybdenum in their routinely available data. This lack of basic information on the molybdenum content of food is an obstacle in our evaluation of molybdenum-rich foods.

Based on information that we do have, our best WHFoods sources of molybdenum tend to fall into the Beans & Legumes group. Our top eight sources of molybdenum all belong to this group, including lentils, dried peas, and the following beans: limas, kidneys, black, soy, pintos, and garbanzos. All eight rank as excellent sources of this mineral. Also included as excellent sources are oats, tomatoes, romaine lettuce, cucumber, and celery. Our very good sources of molybdenum include a second grain (barley) as well as additional vegetables (carrots, bell peppers, and fennel). From our Eggs & Dairy group, eggs and yogurt also qualify as very good sources. It's worth noting here that for some people in the U.S., about 20% of daily molybdenum intake comes from this Eggs & Dairy group, and in some studies of teenagers, this percentage is even higher and can approach about 40%.

Foods from additional food groups—including sesame seeds, walnuts, and almonds from our Nuts & Seeds group, and cod from our Fish group—get added to the molybdenum-rich list when "good" sources of this nutrient are included.

In its analysis of U.S. molybdenum intake, the National Academy of Sciences (NAS) has estimated that adult men in the U.S. average 106 micrograms of dietary molybdenum per day, and adult women average 76 micrograms. Both of these intake levels are well above the adult Dietary Reference Intake (DRI) level for this mineral, which is 45 micrograms. We would also add here that a single serving of any of our top eight molybdenum-rich foods from the Beans & Legumes group provides well over this DRI level.

Introduction to Nutrient Rating System Chart

In order to better help you identify foods that feature a high concentration of nutrients for the calories they contain, we created a Food Rating System. This system allows us to highlight the foods that are especially rich in particular nutrients. The following chart shows the World's Healthiest Foods that are either an excellent, very good, or good source of molybdenum. Next to each food name, you'll find the serving size we used to calculate the food's nutrient composition, the calories contained in the serving, the amount of molybdenum contained in one serving size of the food, the percent Daily Value (DV%) that this amount represents, the nutrient density that we calculated for this food and nutrient, and the rating we established in our rating system. For most of our nutrient ratings, we adopted the government standards for food labeling that are found in the U.S. Food and Drug Administration's "Reference Values for Nutrition Labeling." Read more background information and details of our rating system.

World's Healthiest Foods ranked as quality sources of molybdenum						
Food	Serving Size	Cals	Amount (mcg)	DRI/DV (%)	Nutrient Density	World's Healthiest Foods Rating
Lentils	1 cup	229.7	148.50	330	25.9	excellent
Dried Peas	1 cup	231.3	147.00	327	25.4	excellent
Lima Beans	1 cup	216.2	141.00	313	26.1	excellent
Kidney Beans	1 cup	224.8	132.75	295	23.6	excellent
Soybeans	1 cup	297.6	129.00	287	17.3	excellent
Black Beans	1 cup	227.0	129.00	287	22.7	excellent
Pinto Beans	1 cup	244.5	128.25	285	21.0	excellent
Garbanzo Beans	1 cup	269.0	123.00	273	18.3	excellent
Oats	0.25 cup	151.7	28.86	64	7.6	excellent
Tomatoes	1 cup	32.4	9.00	20	11.1	excellent
Romaine Lettuce	2 cups	16.0	5.64	13	14.1	excellent
Cucumber	1 cup	15.6	5.20	12	13.3	excellent
Celery	1 cup	16.2	5.05	11	12.5	excellent
Barley	0.33 cup	217.1	26.99	60	5.0	very good
Eggs	1 each	77.5	8.50	19	4.4	very good
Carrots	1 cup	50.0	6.10	14	4.9	very good
Bell Peppers	1 cup	28.5	4.60	10	6.5	very good

Fennel	1 cup	27.0	4.35	10	6.5	very good
Yogurt	1 cup	149.4	11.27	25	3.0	good
Peanuts	0.25 cup	206.9	10.77	24	2.1	good
Sesame Seeds	0.25 cup	206.3	10.62	24	2.1	good
Walnuts	0.25 cup	196.2	8.85	20	1.8	good
Green Peas	1 cup	115.7	6.89	15	2.4	good
Almonds	0.25 cup	132.2	6.78	15	2.1	good
Cod	4 oz	96.4	3.86	9	1.6	good

World's Healthiest Foods Rating	Rule
excellent	DRI/DV>=75% OR Density>=7.6 AND DRI/DV>=10%
very good	DRI/DV>=50% OR Density>=3.4 AND DRI/DV>=5%
good	DRI/DV>=25% OR Density>=1.5 AND DRI/DV>=2.5%

Impact of Cooking, Storage and Processing

Like most minerals, we haven't seen any evidence for degradation of molybdenum content in foods when they are stored in keeping with our WHFoods recommendations. We do not, therefore, recommend any specific storage method to enhance mineral nutrition for molybdenum. Instead, we simply encourage you to follow our food-specific storage methods described in each of our individual food profiles. We have not seen good quality research on the loss of molybdenum during cooking. However, since many of our top sources for this mineral involve foods from the Beans & Legumes group, and since our Beans & Legumes rankings for molybdenum are all based on cooked versions of these foods, we have a high level of confidence in their nutrient richness for this mineral, even in cooked form. We have seen some Internet content warning about high levels of molybdenum exposure from stainless steel cookware. While we have seen studies measuring transfer of other minerals (for example, chromium) from stainless steel pots and pans into food, we have not seen studies analyzing molybdenum. Nor have we seen studies showing toxicity from general mineral transfer from cookware into food.

While stainless steel does contain molybdenum, different types of stainless steel can contain widely varying amounts. In general, we like the use of stainless steel in cooking. Like all cookware, we believe that it is important to keep stainless steel in good condition. In this case, "good condition" means maintain smooth food-contact surfaces that are not scratched or abraded. If the inner surfaces of stainless steels pots and pans are no longer smooth and intact, your best option if you want to minimize transfer of stainless steel metals into food is to replace the cookware.

Could it be a good thing for molybdenum to pass from your stainless steel cookware into your food? Unfortunately, we cannot answer this question since we haven't seen studies showing the potential amount of molybdenum that could get transferred. However, it's worth noting that in some situations, migration of minerals from cookware into food can be considered helpful. For example, for a person deficient in iron, transfer of iron from cast-iron cookware into food can help increase iron intake. Once again, we would emphasize the lack of research in this area with respect to stainless steel cookware and molybdenum. In the absence of this research, we continue to support the use of stainless steel in your kitchen, along with the recommendation that you keep your cooking surfaces in good condition.

Risk of Dietary Deficiency

The risk of dietary deficiency of molybdenum in the United States appears to be quite low. As mentioned earlier, the National Academy of Sciences estimated 106 micrograms of daily molybdenum intake for adult men and 76 micrograms for adult women— amounts well above the DRI. We have also seen an earlier 1980 study showing adult intake of about 120 to 240 micrograms of molybdenum per day. All of these numbers fall into the broader range of 80-300 micrograms of dietary molybdenum that we've seen in estimates from other countries.

We are also not aware of reports of symptoms related to dietary deficiency of molybdenum in healthy adults. Typically, reports of deficiency symptoms are common if there is widespread deficiency of a nutrient.

That said, we also see that it is quite possible to eat a diet that does not contain the types of foods that are richest in this mineral. We do recommend including legumes and molybdenum-rich vegetables (like tomatoes, romaine lettuce, cucumbers,

and tomatoes) on a routine basis to ensure healthy molybdenum intake. We would single out the Beans & Legumes group as especially helpful for good molybdenum intake. Ideally, foods from this group would be included in your meal plan at least several days each week to help ensure good molybdenum intake. If you never eat foods from this group, you could still reach your molybdenum goals, but it could be much more challenging for you to do so. A clear exception to this statement would be the following daily food list: hearty intake of our most molybdenum-rich vegetables: tomatoes, romaine lettuce, cucumbers, and celery (providing you with a total of about 25 micrograms of molybdenum), coupled with a serving of yogurt and a serving of walnuts (providing another 20 micrograms). This combination would put you right at the recommended daily amount of 45 micrograms.

Other Circumstances that Might Contribute to Deficiency

With the exception of a single published study on a hospitalized patient in poor physical condition, we haven't seen research documentation on specific events leading to molybdenum deficiency. If common circumstances are able to increase molybdenum deficiency risk, we have yet to see science-based evidence in this regard.

Relationship with Other Nutrients

We sometimes see sources that suggest that too much molybdenum could deplete copper levels. To our knowledge, however, this is only true in ruminant animals like cattle or sheep. We have not seen any credible reports of humans ingesting enough dietary molybdenum to cause depletion of copper or any other nutrient. In keeping with this observation, the National Academy of Sciences did not consider this copper interaction to be relevant for humans in their determination of a Tolerable Upper Intake Limit (UL) for molybdenum.

All of the enzymes that use molybdenum require iron as they are being assembled. Additionally, the sulfite oxidase enzymes use iron in the form of heme (the same iron-containing protein found in red blood cells) along with molybdenum in their detoxification activity. As such, you'll want to make sure your iron nourishment is appropriate to ensure proper molybdenum utilization.

Exposure to the environmental toxin tungsten could potentially interfere with molybdenum metabolism. This is because tungsten can replace molybdenum in its role as an enzyme cofactor. However, tungsten only occurs in the human diet in tiny amounts, and exposure to tungsten is most likely to occur in people exposed on the job (for example, in a factory manufacturing tungsten filaments and coils for light bulbs).

Risk of dietary Toxicity

We are not aware of research showing toxic levels of molybdenum in foods, except in situations involving environmental contamination as mentioned above. As such, we believe that there is little cause for concern about excessive dietary intake of this nutrient in the vast majority of circumstances.

At extreme amounts in animal studies, molybdenum can cause stunted growth, kidney damage, bone loss, anemia, and infertility. None of these potential problems has been observed in humans, however, and we assume this lack of evidence is largely due to the virtual impossibility of consuming such high levels of molybdenum from food, except perhaps in circumstances involving industrial contamination of the environment. (As mentioned earlier, if too much molybdenum gets released from a manufacturing facility and plants and animals in the immediate area get exposed to excessive molybdenum, and then humans living in the area consume those plants and animals for food, it is definitely possible for this scenario to result in excessive dietary intake of molybdenum.) However, this type of dietary exposure is definitely the exception and not the rule.

As mentioned earlier, the National Academy of Sciences (NAS) has established a Tolerable Upper Intake Level (UL) of 2 milligrams, or mg (the same as 2,000 micrograms, or mcg) for adult men and women 19 years and older. For younger persons, the ULs are as follows.

- 1-3 years: 0.6 mg (600 mcg)
- 9-13 years: 1.1 mg (1,100 mcg)
- 14-19 years: 1.7 mg (1,700 mcg)
- 19+ years: 2.0 mg (2,000 mcg)

Two other categories of ULs are as follows.

- Pregnant or lactating women, under 19 years: 1.7 mg (1,700 mcg)

- Pregnant or lactating women, over 19 years: 2.0 mg (2,000 mcg)

Disease Checklist

- Sulfite sensitivity
- Asthma
- Poor detoxification
- Cardiovascular risk
- Metabolic syndrome

Public Health Recommendations

In 2001, the National Academy of Sciences established Dietary Reference Intakes (DRIs) for molybdenum. These DRIs are summarized in the chart below. Note that the DRI recommendation for infants under one year of age comes in the form of an Adequate Intake (AI) level, and all other recommendations come in the form of a Recommended Dietary Intake (RDA).

- 0-6 months: 2 mcg
- 6-12 months: 3 mcg
- 1-3 years: 17 mcg
- 4-8 years: 22 mcg
- 9-13 years: 34 mcg
- 14-18 years: 43 mcg
- 19+ years: 45 mcg
- Pregnant and lactating women: 50 mg

The DRI report for molybdenum also established a Tolerable Upper Intake Levels (ULs) as follows.

- 1-3 years: 0.6 mg (600 mcg)
- 9-13 years: 1.1 mg (1,100 mcg)
- 14-19 years: 1.7 mg (1,700 mcg)
- 19+ years: 2.0 mg (2,000 mcg)
- Pregnant or lactating women, under 19 years: 1.7 mg (1,700 mcg)
- Pregnant or lactating women, over 19 years: 2.0 mg (2,000 mcg)

The Daily Value (DV) for molybdenum is 75 micrograms (mcg) per day. This is the standard that you will see on food and supplement labels.

At WHFoods, we have adopted the adult DRI for molybdenum of 45 micrograms (mcg) as our recommended daily intake level.

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The World's Healthiest Foods

World's Healthiest Foods rich in omega-3 fats		
Food	**Cals**	**DRI/DV**
Flaxseeds	75	133%
Walnuts	196	113%
Sardines	189	61%
Salmon	158	55%
Beef	175	46%
Soybeans	298	43%
Tofu	164	28%
Shrimp	135	14%
Brussels Sprouts	56	11%
Cauliflower	29	9%

Basic Description

No type of fat has been getting more recent publicity than omega-3s, and you're very likely to have seen TV ads or heard radio infomercials about this unique type of fat. However, much of the omega-3 publicity you've heard has probably been focused on dietary supplements rather than food. In this profile, we'll provide you with a fresh look at omega-3s from the perspective of food and the best ways to balance your meal plan for strong omega-3 support.

Omega-3s belong to a broader group of fats called polyunsaturated fats. Sometimes you'll hear this group called "poly" fats. The specific members of this group are called polyunsaturated fatty acids, or PUFAs. What's most important about PUFAs—including omega-3s—is one special aspect of their chemical structure. They contain what are called "double bonds"—special connections that make them more flexible and interactive as fatty acids; they also make them more delicate and susceptible to damage. All PUFAs—including all omega-3s—contain at least two double bonds. But the position of the double bonds in omega-3s is unique and simply not found in other fats.

Some omega-3s are simpler than others. The simplest is called alpha-linolenic acid, or ALA. Like most vitamins, ALA is especially important in our diet because our bodies cannot make it from scratch. Either we consume it, or we don't have enough. Fortunately for us, many commonly eaten plant and animal foods contain ALA.

For other omega-3s, this all-or-nothing scenario is not the case. Under the right circumstances, our bodies can usually take ALA and transform it into other omega-3s. These other omega-3s are more complicated than ALA and contain more double bonds. The best studied are EPA (eicosapentaenoic acid) and DHA (docosahexaenoic acid). EPA has five double bonds and DHA has six. In a large number of research studies, there are clear health benefits provided by EPA and DHA that are not provided by ALA. These health benefits involve support of many body systems and decreased risk of many chronic diseases.

So without question, our bodies need ALA, EPA, and DHA to stay healthy, and we need to consume ALA-containing foods no matter what because our bodies lack the ability to make ALA. But what about EPA and DHA? Are we absolutely required to eat foods containing EPA and DHA?

The answer to that question is particularly important since it can affect our entire approach to eating. If we only need to eat ALA-containing foods—and can trust our bodies to make all of the EPA and DHA that we need—we become free to choose whatever type of diet we would like, including a strict vegan diet that contains no animal foods whatsoever (including no milk, no cheese, and no eggs). That's because a wide variety of plant foods contain small-to-moderate amounts of ALA. However, if we need to obtain EPA and DHA directly from food, we become much more restricted in our food choices. For example, if we are trying to implement a strict vegan diet with no animal foods whatsoever and want to obtain DHA from our diet, our choices would most likely be limited to sea plants (which can contain DHA) or some fermented foods (like fermented soy foods) which had been allowed to ferment with the help of specific fungi that were capable of producing DHA. The absence of DHA in land plants is the reason for these very limited options.

Let's take some other examples. If we wanted to consume a generally vegetarian diet while still allowing ourselves to consume some fish, we would be able to get EPA and DHA from our food since fish can be a rich source of EPA and DHA. Similarly, if we wanted to consume a generally vegetarian diet while still allowing ourselves to consume some cheese, yogurt, milk, or

eggs, we could also figure out how to obtain sufficient amounts of EPA and DHA from our food since these foods can contain both EPA and DHA. Or if we chose to eat meat while avoiding all fish, it would still be possible for us to get our EPA and DHA since meats can contain both EPA and DHA. (Their EPA and DHA content require that the cattle to have eaten a healthy amount plants that contain omega-3s.) The table below summarizes some of these basic relationships between omega-3s and diet types.

Diet Type	ALA Food Sources	EPA and DHA Food Sources
Vegan	many plants	sea plants; possibly land plant foods when fermented with the help of certain fungi
Generally vegetarian but including fish	many plants and most fish	most fish; sea plants; possibly land plant foods when fermented with the help of certain fungi
Generally vegetarian but including eggs, cheese, milk and yogurt (without fish, sea plants, or meat)	many plants; eggs, cheese, milk, and yogurt	eggs, cheese, milk, and yogurt, especially when obtained from grass-fed animals but in varying amounts depending on additional factors; possibly land plant foods when fermented with the help of certain fungi
Plant-eating and meat-eating (but without fish or sea plants)	many plants; many meats	many meats, especially when obtained from grass-fed animals, but in varying amounts, depending on additional factors; possibly land plant foods when fermented with the help of certain fungi

As you can see from the table above, our food choices can change quite dramatically if we are required to obtain EPA and DHA from our diet. But are we required to do so? Unfortunately, the answer to this question is not 100% clear from the research studies.

In principle, most healthy persons should be able to eat ALA-containing foods (like flaxseeds, walnuts, tofu, and spinach) and then rely on their bodies to convert ALA into EPA and DHA. Yet there is considerable scientific debate about our ability to get optimal amounts of EPA and DHA by relying exclusively on ALA-containing foods. That's because our body's ability to make EPA and DHA from ALA can become compromised under a variety of common circumstances.

For example, our body's ability to make EPA and DHA from ALA partly depends on the other types of fat that we eat. One of those other fat types is omega-6 fat. Omega-6 fats are more plentiful in foods than omega-3 fats. Because they are more plentiful, we often find ourselves consuming much more of them. Yet high consumption of omega-6 fats can directly reduce the amount of ALA that our body converts into EPA and DHA.

Or, to take another example: our body cannot do an effective job of converting ALA into EPA and DHA without a satisfactory supply of certain nutrients. These nutrients include vitamin B3, vitamin B6, vitamin C, and the minerals zinc and magnesium. If we are deficient in one or more of these nutrients, our bodies may not be able to provide us with optimal amounts of EPA and DHA, even when our ALA intake is sufficient.

Different people will want to use different dietary approaches to obtain their omega-3s. But based on a review of the research and on the chart information presented above, here are our basic recommendations:

- If you choose to avoid all animal foods (including seafoods), we recommend a discussion with your healthcare practitioner to determine possible supplementation with omega-3s.
- If you consume animal foods but avoid seafoods, we recommend extra care in selection of EPA- and DHA-containing animal foods. Animals that have consumed healthy amounts of omega-3s in their diet will be the most likely to contain EPA and DHA. As a general rule, these animals will have been raised in a natural setting throughout their lives and pasture-fed on a variety of grasses, legumes, and other plants.
- If your diet includes fish, 2-3 servings per week is a good target level for bringing fish-based EPA and DHA into your meal plan.

Omega-3 fatty acids are a group of polyunsaturated fats found in a wide variety of foods, most famously in fish. Because of recent research suggesting potential cardiovascular prevention and other health benefits, omega-3 fatty acids are currently a hot topic in nutrition research.

Of the World's Healthiest Foods, two (flaxseeds and walnuts) rate as excellent sources. We rate five of our listed foods as very good sources of omega-3, and 19 as good sources. This should give you plenty of choices to make sure your diet contains good sources of these important fats.

Role in Health Support

ALA, EPA, and DHA all play important roles in support of our health. Yet these roles are somewhat different.

Alpha-linolenic acid (ALA)

A large amount of ALA is sometimes used strictly for energy purposes. Our bodies can take ALA and use it to produce energy for our cells. In some situations, most of the ALA that we consume will get used in this way. ALA is also the primary building block for EPA and DHA. It's difficult to overstate the importance of ALA in this regard. Our immune, inflammatory, cardiovascular, and nervous systems simply cannot function correctly without sufficient amounts of EPA and DHA. When we don't have enough ALA, we don't have enough EPA and DHA (unless we've eaten foods that contain them). So ALA has a critical role to play in the health of many body systems as the key building block for EPA and DHA. There are basically two important metabolic roles for dietary ALA. The first is the breakdown of ALA to be used as an energy source. As much as 85% of dietary ALA is broken down to be used as an energy source.

The other major role for ALA is to be elongated to the related omega-3 fats EPA and DHA. The efficiency of this process will be discussed in more detail below.

Eicosapentaenoic acid (EPA)

Proper function of our inflammatory system depends on the presence of messaging molecules called prostaglandins. Many of these prostaglandins are made directly from EPA. Equally important, most of the prostaglandins made from EPA tend to be anti-inflammatory in their effect. Therefore, your risk of excessive inflammation and inflammation-related disease can be lowered through consumption of foods rich in EPA.

Docosahexaenoic acid (DHA)

Proper function of our nervous system—including our brain—depends on the presence of DHA. DHA is particularly important to brain function. Our brain is 60% fat by weight, and DHA makes up an average of 15 to 20% of all fat in our brain. If we tie these two facts together, we arrive at the following conclusion: DHA accounts for 9-12% of our brain's total weight! Drops in brain DHA levels are known to associate with cognitive impairment or slower neurological development in children. Nervous system deficiencies of DHA have been associated with a wide variety of problems, including neurodegenerative diseases like Parkinson's disease; cognitive problems including reasoning ability in children; and severity of multiple sclerosis.

A Special Note about Omega-3s and Cardiovascular Support

Prevention of cardiovascular diseases is one of the best-studied and substantiated role for omega-3s in the diet. Especially strong is the research supporting EPA and DHA in lowering heart disease risk. There is less research on ALA and heart disease, but research in this area still shows the ability of ALA intake to decrease risk. Unfortunately, the research we see in this area continues to focus more on dietary supplements than food, and in the future, we hope to see a much stronger emphasis on omega-3s from food.

The most crucial role for omega-3 fatty acids in health is arguably in prevention of cardiovascular diseases like heart attack and stroke. Much of the research in this area looks specifically at total EPA + DHA intake from diet and/or supplements.

Although there is comparatively less research on the topic, ALA intakes are associated with lower risk of cardiovascular disease independently of the other omega-3 fats. Still, the beneficial effects of diets high in ALA are likely to be more modest than diets rich in EPA and DHA.

Summary of Food Sources

Excellent sources of alpha-linolenic acid (ALA) include flaxseeds and walnuts. Very good sources of ALA include sardines and salmon, as well as cauliflower, Brussels sprouts, and mustard seeds. Good sources include a wide variety of vegetables (collard and turnip greens, spinach, kale, green beans, romaine lettuce, summer squash, and winter squash), fish (scallops, shrimp, and cod), legumes and foods made from legumes (soybeans, tofu, and miso), and fruits (strawberries and, raspberries). While seafood is known for its EPA and DHA content, smaller amounts of ALA are provided by numerous seafoods. While not ranked on our Rating System Chart, animal foods including beef, dairy, and eggs may also provide varying amounts of ALA. Outside of the U.S., one study in Britain found that about 25% of ALA intake in the UK population came from fish and

meat dishes, with another 8% from eggs and dairy foods. While we do not have a similar study from the U.S., we do know that the quantity of ALA in animal foods depends on the diet consumed by the animals. As a general rule, animals raised in a natural setting throughout their lives and pasture-fed on a variety of grasses, legumes, and other plants will contain more ALA in their bodies, and will therefore provide food that is richer in ALA, eicosapentaenioc acid (EPA) and docosahexaenoic acid (DHA). Seafood is the food group most concentrated in EPA and DHA.

Like all creatures, fish have an omega-3 content that is highly dependent on their diet. If they eat algae, sea plants, and other foods that are rich in omega-3s, they are able to store more omega-3s in their tissue. If they live in a habitat where omega-3s are not widely available, they store much less. The close relationship between their diet and their omega-3 content applies to all specific omega-3s found in fish, including ALA, EPA, and DHA. It also applies to all types of fish including wild-caught and farmed. Some farmed fish are fed processed omega-3 concentrates to boost their omega-3 content. Other farmed fish are fed few omega-3s and have lower-than average omega-3 content.

Land animals are no different than fish in terms of their omega-3 content. Their diet is the key controlling factor—the same as it is for ocean creatures. Cows and chickens consuming diets that are rich in omega-3s tend to produce milk and eggs that are higher in omega-3 fats. Levels of omega-3s in eggs can reach levels of 350 milligrams per egg, depending on the hen's diet. In cow's milk, omega-3 levels have been shown to reach 155 milligrams per 8-ounce cup in some grass-fed heifers. About half of these omega-3s are typically present in the form of ALA, with the other half being divided between EPA, DHA, and other omega-3s. As a general rule, the milk, cheese, yogurt, and eggs obtained from land animals that have been grass-fed and have had natural access to pasture plants containing omega-3s are going to be your best bet for omega-3s from land animals.

Other omega-3 fortified foods are becoming available on the market, including margarine spreads, juices, and snack foods. These foods are generally made by adding the fatty acids during the manufacturing process. As with all nutrients, we believe that your omega-3s are best obtained from whole, natural foods. Unless a food is whole and natural, there is no way to guarantee that its nutrients will be found in optimal ratios and balanced proportions, or even incorporated into the food matrix in an optimal way.

We would like to add a special note about one food that does not appear on our ranking list as a good, very good, or excellent source of omega-3s. That food is tuna. In our nutrient analysis, we used baked yellowfin tuna. A 4-ounce serving of this form of tuna provided 140 milligrams of omega-3s and 147 calories. When we put these numbers into our rating system formula, tuna provided too few omega-3s in comparison with its calorie content to rank as a good source of omega-3s. However, we do not believe that this outcome would automatically be true for all tuna. We've seen studies on canned light tuna that showed about 345 milligrams of omega-3s in 4 ounces, and in the case of canned albacore tuna, we've seen studies showing about 975 milligrams of omega-3s in 4 ounces. Their higher levels of omega-3s would change the status of tuna in our rating system. However, our approach to healthy eating is always focused on fresh, natural, and minimally processed foods rather than canned or other versions.

Introduction to Nutrient Rating System Chart

In order to better help you identify foods that feature a high concentration of nutrients for the calories they contain, we created a Food Rating System. This system allows us to highlight the foods that are especially rich in particular nutrients. The following chart shows the World's Healthiest Foods that are either an excellent, very good, or good source of omega-3 fats. Next to each food name, you'll find the serving size we used to calculate the food's nutrient composition, the calories contained in the serving, the amount of omega-3 fats contained in one serving size of the food, the percent Daily Value (DV%) that this amount represents, the nutrient density that we calculated for this food and nutrient, and the rating we established in our rating system. For most of our nutrient ratings, we adopted the government standards for food labeling that are found in the U.S. Food and Drug Administration's "Reference Values for Nutrition Labeling." Read more background information and details of our rating system.

World's Healthiest Foods ranked as quality sources of omega-3 fats						
Food	Serving Size	Cals	Amount (g)	DRI/DV (%)	Nutrient Density	World's Healthiest Foods Rating
Flaxseeds	2 TBS	74.8	3.19	133	32.0	excellent
Walnuts	0.25 cup	196.2	2.72	113	10.4	excellent
Sardines	3.20 oz	188.7	1.46	61	5.8	very good
Salmon	4 oz	157.6	1.32	55	6.3	very good
Beef	4 oz	175.0	1.10	46	4.7	very good
Brussels Sprouts	1 cup	56.2	0.27	11	3.6	very good

Cauliflower	1 cup	28.5	0.21	9	5.5	very good
Mustard Seeds	2 tsp	20.3	0.15	6	5.5	very good
Soybeans	1 cup	297.6	1.03	43	2.6	good
Tofu	4 oz	164.4	0.66	28	3.0	good
Shrimp	4 oz	134.9	0.34	14	1.9	good
Winter Squash	1 cup	75.8	0.19	8	1.9	good
Broccoli	1 cup	54.6	0.19	8	2.6	good
Cod	4 oz	96.4	0.19	8	1.5	good
Collard Greens	1 cup	62.7	0.18	8	2.2	good
Spinach	1 cup	41.4	0.17	7	3.1	good
Summer Squash	1 cup	36.0	0.15	6	3.1	good
Raspberries	1 cup	64.0	0.15	6	1.8	good
Kale	1 cup	36.4	0.13	5	2.7	good
Romaine Lettuce	2 cups	16.0	0.11	5	5.2	good
Green Beans	1 cup	43.8	0.11	5	1.9	good
Strawberries	1 cup	46.1	0.09	4	1.5	good
Turnip Greens	1 cup	28.8	0.09	4	2.3	good
Miso	1 TBS	34.2	0.08	3	1.8	good
Bok Choy	1 cup	20.4	0.07	3	2.6	good
Leeks	1 cup	32.2	0.07	3	1.6	good
Basil	0.50 cup	4.9	0.07	3	10.8	good

World's Healthiest Foods Rating	Rule
excellent	DRI/DV>=75% OR Density>=7.6 AND DRI/DV>=10%
very good	DRI/DV>=50% OR Density>=3.4 AND DRI/DV>=5%
good	DRI/DV>=25% OR Density>=1.5 AND DRI/DV>=2.5%

Impact of Cooking, Storage and Processing

Omega-3 fatty acids are very susceptible to free radical damage. Oxidation of omega-3 fats limits their shelf life and their ability to provide you with the nourishment you need. Damage to the omega-3s in your food can be caused by light, oxygen, or heat. For this reason, foods that are rich in omega-3s should usually be stored in the refrigerator in a sealed container. This rule not only applies to animal foods like fish, dairy, eggs, and meat but also to plant foods like nuts and seeds.

The grinding of nuts and seeds deserves special mention in terms of its impact on omega-3 nourishment. As described earlier, many nuts and seeds contain valuable amounts of omega-3s in the form of ALA. However, in the case of small seeds like flax or chia seeds, it can be very difficult to chew the seeds and grind them sufficiently with your teeth to help increase the availability of their ALA. For this reason, many people choose to grind seeds (for example, in a coffee grinder) prior to eating or incorporating into a recipe. If you decide to grind your omega-3 rich seeds, their shelf life will be reduced and it becomes especially important to store them in a sealed, opaque container in your refrigerator. To give you a more practical idea of shelf life, pre-ground flaxseeds—packaged by the manufacturer in a gas-flushed, light-protective pouch—will typically last for 6-16 weeks before going bad. By comparison, whole flaxseeds will last 6-12 months when stored properly. If you are grinding your own seeds, we recommend a more modest storage time of 1-2 months.

Risk of Dietary Deficiency

If your meal plan resembles that of the average U.S. adult, you are highly likely to be deficient in omega-3s. The reason is simple: the average U.S. adult consumes too few foods that are good sources of omega-3s, and excessive amounts of total fat that contain too many omega-6s.

In the U.S., our ratio of omega-6:omega-3 fat has been estimated to fall between 20:1 and 8:1. (Those numbers mean that we eat at least eight times more omega-6 than omega-3, and perhaps as much as 20 times more.) Most studies suggest that a

healthier ratio of omega-6:omega-3 lies between 4:1 and 2:1. Taken as a whole, the dietary circumstances described above leave the average U.S. adult with an insufficient intake of ALA and a compromised ability to convert ALA into other health-supportive omega-3s like EPA and DHA due to excessive intake of omega-6s.

A further problem with the average U.S. diet and omega-3s is deficient intake of nutrients required to convert ALA into EPA and DHA. This list of nutrients includes vitamins B3, B6, and C, and the minerals zinc and magnesium.

Reasons for low omega-3 intake in the U.S. diet vary, but some key reasons that apply to many meal plans are as follows:

- Low intake of nuts and seeds. The most commonly eaten nuts in the U.S. are peanuts, and, while healthy and delicious, peanuts technically fall into the category of legumes rather than nuts and are therefore less concentrated in omega-3s. Unlike true nuts (like walnuts) or seeds (like flaxseeds), peanuts do not show up in our Top 25 list of WHFoods that provide you with omega-3s and do not rank as an excellent, very good, or good source of these fatty acids. (Peanuts typically provide you with about 5-10 milligrams of omega-3s per ounce.)
- High intake of meat and dairy products from animals that did not graze on plants containing omega-3s. The vast majority of beef, milk, cheese, and yogurt consumed in the U.S. comes from cows that did not have the opportunity to eat pasture plants containing omega-3s. Similarly, the vast majority of chicken and eggs consumed in the U.S. comes from animals raised without the benefit of omega-3 containing plants.
- Infrequent intake of fish, especially fish richer in omega-3s like salmon, halibut, and/or sardines.

Your best ways of increasing omega-3 nourishment are to reverse all of the above practices. Consider increasing your intake of nuts (like walnuts) or seeds (like flaxseeds). Consumption of these foods on a daily basis can work well in most meal plans. Also consider fish like salmon, sardines, shrimp, or cod on a more frequent basis. Finally, consider purchase of grass-fed and/or pastured-raised animal foods including meats, cheeses, yogurt, and eggs.

If you are following a fairly strict vegetarian or vegan diet, it may be especially difficult for you to get EPA and DHA you directly from food. (That's because animal foods are typically richer sources of these omega-3s than plant foods.) For this reason, we recommend that you increase your intake of ALA-containing foods to a level that will provide you with approximately 4 grams of ALA per day. Here are some choices that can help you reach that 4 gram level.

Food	ALA Serving Size	ALA
Flaxseeds	2 tablespoons	3.19 grams
Walnuts	1/4 cup	2.72 grams
Tofu	8 ounces	1.32 grams
Brussels sprouts	2 cups cooked	0.54 grams
Cauliflower	2 cups cooked	0.52 grams

Although we have partially addressed the following issue earlier in this article, we would like to emphasize one ongoing controversy that continues to hang over omega-3 research related to risk of dietary deficiency. That controversy involves metabolism of omega-3s. Researchers know that humans need all forms of omega-3s—including the forms ALA, EPA, and DHA. Researchers also know that humans can take ALA and convert it into EPA and DHA under favorable circumstances. But researchers still don't know is exactly how often these favorable circumstances exist. Because the research jury on omega-3 metabolism is still out, we recommend taking one of two approaches to your omega-3 nourishment. A first approach is to focus on including not only ALA-rich plant foods in your meal plan, but EPA-rich and DHA-rich animal foods as well. A second approach is to focus exclusively on ALA-rich foods in your meal plan, but greatly increase your intake to the 4 gram level described earlier.

Other Circumstances that Might Contribute to Deficiency

Since omega-3s are a type of fat, some conditions that involve poor absorption of fats from our digestive tract can increase our risk of omega-3 deficiency. Included in this list of conditions would be inflammatory bowel disease, celiac disease, and cystic fibrosis.

Relationship with Other Nutrients

Since omega-3 fats are delicate and susceptible to damage from oxygen-containing molecules, our need for dietary antioxidants becomes greater as our intake of polyunsaturated fats goes up. Especially important within this increased antioxidant intake is increase intake of vitamin E. Our WHFoods richest in vitamin E include sunflower seeds, spinach, Swiss

chard, turnip greens, asparagus, mustard greens, chili peppers, almonds, broccoli, and bell peppers. For more information about vitamin E-containing foods, please see our nutrient profile for vitamin E.

As described earlier, excessive intake of omega-6 fats in comparison to omega-3s can compromise your omega-3 nourishment. In practical terms, excessive intake of omega-6s typically comes from one or more of three places. First is excessive intake of total fat. (Too much overall fat consumption can result in excessive intake of omega-6s because most fat-containing foods provide more omega-6s than omega-3s.) Second is excessive use of cooking oils high in omega-6s (including corn oil, safflower oil, sunflower seed oil, and soybean oil). Third is excessive intake of fried foods. (The oils used for frying are typically richest in omega-6s.) Cutting back in any or all of these three areas can greatly reduce your omega-6 intake.

Risk of dietary Toxicity

There is no known toxicity risk consistently associated with diets high in omega-3 fatty acids. Like any fatty acids, omega-3s are densely packed calorie sources, and too much dietary fat can be associated with weight gain. However, if you restrict your intake of high-fat foods to foods that are rich in omega-3s, you're less likely to overdo it on the calories. It's almost never the omega-3 rich foods that we tend to consume in excess.

Disease Checklist

- Cardiovascular disease (prevention in high risk individuals)
- Hypertension
- High cholesterol
- Diabetes
- Alzheimer's disease
- Cognitive problems in aging
- Parkinson's disease
- Multiple sclerosis
- Excessive blood clotting
- Brain/nervous system support
- Pregnancy / lactation
- Depression, including post-partum depression (prevention)
- PMS (flaxseed only)
- Fibrocystic breast disease (flaxseed only)
- Hot flashes (flaxseed only)

ALA forms of omega-3 fatty acids may play a role in the prevention and/or treatment of the following health conditions:

- Cardiovascular disease
- Hypertension
- Excessive blood clotting
- Pregnancy/lactation
- PMS
- Fibrocystic breast disease
- Hot flashes

EPA and DHA forms of omega-3 fatty acids may play a role in the prevention and/or treatment of the following health conditions:

- Cardiovascular disease
- Hypertension
- High cholesterol
- Diabetes
- Excessive blood clotting
- Alzheimer's disease
- Cognitive decline
- Parkinson's disease
- Multiple sclerosis
- Nervous system development
- Depression
- Bipolar disorder

- Pregnancy/lactation

Public Health Recommendations

We've found specific omega-3 recommendations from a variety of public health organizations, including the National Academy of Sciences, American Heart Association, American Dietetic Association, World Health Organization, and National Institutes of Health. These recommendations are relatively similar, but by no means identical. We've provided you with more details below, but we also want to give you our own WHFoods recommendations based on the research studies that we have reviewed.

Summary of Omega-3 Reccomendations

- Total omega-3 fats: at least 2.5 grams per day
- EPA+DHA included within your total omega-3s: 400-500 milligrams per day

For total omega-3 fat, we recommend an average of at least 2.5 grams per day. On some days you might get slightly less, but over the course of an entire week, you'll want to average at least this amount. Our Healthiest Way of Eating Plan averages about 3 grams of omega-3s per day, and it will give you a very practical look at what it takes to provide this amount on a meal-by-meal basis.

Within these 2.5 grams of total omega-3s, we recommend an average daily intake of 400-500 milligrams of EPA and DHA combined. Since you can get over 1,000 milligrams from a 4-ounce serving of fish like salmon, three servings of salmon per week could bring your daily EPA and DHA average to this level all by itself. Grass-fed beef and dairy products cannot usually provide you with amounts of EPA and DHA equivalent to fish, but they can still increase your EPA and DHA intake substantially.

More details about public health organizations and their recommendations are as follows.

The National Academy of Sciences has established a Dietary Reference Intake (DRI) level for ALA at 1.6 grams per day for men ages 19-70 and to 1.1 grams per day for women ages 19-70. An expert working group at the National Institutes of Health (NIH) has suggested an intake of 2.2 grams of ALA per 2000 dietary calories for both women and men.

There are several recommendations for intake of EPA and DHA from different groups. These recommendations include:

- The American Dietetic Association recommends an average of 500 mg of total EPA and DHA per day. This would be approximated by having two 4-ounce (after cooking) servings of fatty fish per week.
- The American Heart Association recommends two servings of fish per week, preferably fatty fish.
- The World Health Organization recommends one to two servings of fish per week, with each serving providing between 200 and 500 mg of total EPA and DHA.
- The NIH (National Institutes of Health) working group recommends 220 mg each of EPA and DHA per day in a 2000-calorie diet.

There are also some specific recommendations for target populations. These include:

- The Child Health Foundation recommends that pregnant and lactating women should receive an average of at least 200 mg per day of DHA.
- The American Heart Association recommends a total of 1000 mg EPA and DHA for people with documented coronary artery disease.

The National Academy of Sciences has not issued a Tolerable Upper Intake Limit (UL) for omega-3 fatty acids. Similarly, none of the other experts listed above have recommended limiting omega-3 intake below a certain standard.

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The World's Healthiest Foods

World's Healthiest Foods rich in pantothenic acid		
Food	Cals	DRI/DV
Mushrooms, Shiitake	41	52%
Avocado	240	42%
Sweet Potato	180	35%
Lentils	230	25%
Dried Peas	231	23%
Mushrooms, Crimini	16	22%
Chicken	187	22%
Turkey	167	20%
Yogurt	149	19%
Broccoli	55	19%

Basic Description

Pantothenic acid (also known historically as vitamin B5) is among the most important of the B vitamins for the basic processes of life while also being one of the less likely nutrient deficiencies in the average U.S. diet.

One factor helping to prevent pantothenic acid deficiency is the U.S. diet is its common presence in so many different foods. In fact, the common presence of pantothenic acid in foods is referred to in the naming of this vitamin, since the word *pantothen* in Greek translates as "on all sides" or "from all "quarters." Among our 100 core WHFoods, 99% contain some measurable amount of pantothenic acid! (Only one of our foods lacks pantothenic acid, and that food is olive oil. While olives themselves contain a small amount of this vitamin, this small amount is lost when the oil is pressed out of the olives since the oil is 100% fat and pantothenic acid is a water-soluble vitamin.)

Without pantothenic acid, you would be unable to use fats, carbohydrates, or proteins as energy sources. You would also be unable to make hormones and your immune system would collapse. These are only some of the important functions that pantothenic acid has.

We list three excellent sources of pantothenic acid—cauliflower, crimini mushrooms, and shiitake mushrooms. We list eight very good sources and 38 good sources.

Role in Health Support

Energy Production

The most studied role of pantothenic acid in health support is its incorporation into a molecule called Coenzyme A (CoA). This molecule is arguably on the short list of the most important chemicals needed to sustain life. In fact, CoA is so important that one recent research group suggested that the origin of life could be traced back to the evolution of this chemical.

CoA occupies a central place in energy metabolism, acting to allow carbohydrates, fats, and proteins to be burned as fuel sources. Given this critical role, it is a very good thing that pantothenic acid is so ubiquitous in foods. We wouldn't exist without it.

Fat Metabolism

In addition to breaking down fats as fuel, pantothenic acid—via the CoA molecule—is necessary for building fats for storage. You'll also need CoA to build cholesterol in the body, which in turn acts as a building block for key hormones that guide metabolic processes. (While many public health organizations warn about risks related to excess presence of cholesterol in the body, a certain amount of cholesterol is critical for health since many types of cells require cholesterol in their membranes and cholesterol is also required for production of certain hormones and vitamin D production.)

While some readers may be concerned about extra fat storage, and might wonder if they could lower their risk of extra fat storage by somehow blocking pantothenic acid activity or deliberately making themselves deficient in pantothenic acid, we are not are of any research evidence showing this strategy to potentially effective, potentially safe, or potentially advisable in any way. We certainly wouldn't recommend trying any personal experimenting of this kind.

Summary of Food Sources

It is probably easier for us to ask the question "What foods don't contain pantothenic acid?" than it is for us to quickly discuss the most rich food sources. As described earlier, 99/100 WHFoods contain measurable amounts of this vitamin, and nearly half of our foods (49/100) provide pantothenic acid in good, very good, or excellent amounts. The vast majority of our Herbs & Spices also contain measurable amounts of this vitamin.

In our food rating system, all of our top 10 foods for pantothenic acid are vegetables. Included in this group are root vegetables such as sweet potatoes, leafy vegetables such as turnip greens, stems such as asparagus, and also mushrooms. Moving on from our top 10 to our top 25, however, we come across a wide diversity of food groups that provide pantothenic acid, including fruit, legumes, grains, fish, animal meats, eggs, and dairy foods. This diversity of food groups reflects the fact that pantothenic acid is truly *pantothen*, meaning "found in all quarters."

Some of our nutrients are quite concentrated in specific foods. For these nutrients, it is sometimes a fun exercise to concentrate the daily requirements into a couple of foods or recipes as we do here in the niacin article. This is not as easy for pantothenic acid, however since the sources are much more spread throughout the diet.

Instead, as we build a daily diet for pantothenic acid nutrition, we should focus on the variety of foods this diet draws upon. Let's start in the morning with Poached Eggs Over Spinach and Mushrooms and some papaya. At lunch, let's go with Healthy Veggie Salad and some yogurt. At dinner, we'll choose 15-Minute Asian Tuna. All three of these meals contain more than half our daily requirement for pantothenic acid.

This diet rich in pantothenic acid looks a lot like a microcosm of the World's Healthiest Foods approach. We have rich and varied fruits and vegetables. We'll also have a little bit of eggs, and a small amount of fish at dinner.

Introduction to Nutrient Rating System Chart

In order to better help you identify foods that feature a high concentration of nutrients for the calories they contain, we created a Food Rating System. This system allows us to highlight the foods that are especially rich in particular nutrients. The following chart shows the World's Healthiest Foods that are either an excellent, very good, or good source of pantothenic acid. Next to each food name, you'll find the serving size we used to calculate the food's nutrient composition, the calories contained in the serving, the amount of pantothenic acid contained in one serving size of the food, the percent Daily Value (DV%) that this amount represents, the nutrient density that we calculated for this food and nutrient, and the rating we established in our rating system. For most of our nutrient ratings, we adopted the government standards for food labeling that are found in the U.S. Food and Drug Administration's "Reference Values for Nutrition Labeling." Read more background information and details of our rating system.

World's Healthiest Foods ranked as quality sources of pantothenic acid						
Food	Serving Size	Cals	Amount (mg)	DRI/DV (%)	Nutrient Density	World's Healthiest Foods Rating
Mushrooms, Shiitake	0.50 cup	40.6	2.61	52	23.1	excellent
Mushrooms, Crimini	1 cup	15.8	1.08	22	24.5	excellent
Cauliflower	1 cup	28.5	0.63	13	8.0	excellent
Sweet Potato	1 cup	180.0	1.77	35	3.5	very good
Broccoli	1 cup	54.6	0.96	19	6.3	very good
Beet Greens	1 cup	38.9	0.47	9	4.4	very good
Asparagus	1 cup	39.6	0.40	8	3.6	very good
Turnip Greens	1 cup	28.8	0.39	8	4.9	very good
Bell Peppers	1 cup	28.5	0.29	6	3.7	very good
Cucumber	1 cup	15.6	0.27	5	6.2	very good
Celery	1 cup	16.2	0.25	5	5.6	very good

Avocado	1 cup	240.0	2.08	42	3.1	good
Lentils	1 cup	229.7	1.26	25	2.0	good
Dried Peas	1 cup	231.3	1.17	23	1.8	good
Chicken	4 oz	187.1	1.09	22	2.1	good
Turkey	4 oz	166.7	1.02	20	2.2	good
Yogurt	1 cup	149.4	0.95	19	2.3	good
Salmon	4 oz	157.6	0.92	18	2.1	good
Rye	0.33 cup	188.5	0.81	16	1.5	good
Beef	4 oz	175.0	0.77	15	1.6	good
Eggs	1 each	77.5	0.70	14	3.3	good
Potatoes	1 cup	160.9	0.65	13	1.5	good
Wheat	1 cup	151.1	0.63	13	1.5	good
Corn	1 each	73.9	0.61	12	3.0	good
Shrimp	4 oz	134.9	0.59	12	1.6	good
Papaya	1 medium	118.7	0.53	11	1.6	good
Winter Squash	1 cup	75.8	0.48	10	2.3	good
Cow's milk	4 oz	74.4	0.46	9	2.2	good
Cod	4 oz	96.4	0.41	8	1.5	good
Collard Greens	1 cup	62.7	0.41	8	2.4	good
Raspberries	1 cup	64.0	0.40	8	2.3	good
Brussels Sprouts	1 cup	56.2	0.39	8	2.5	good
Grapefruit	0.50 medium	41.0	0.36	7	3.2	good
Pineapple	1 cup	82.5	0.35	7	1.5	good
Watermelon	1 cup	45.6	0.34	7	2.7	good
Carrots	1 cup	50.0	0.33	7	2.4	good
Oranges	1 medium	61.6	0.33	7	1.9	good
Cranberries	1 cup	46.0	0.29	6	2.3	good
Swiss Chard	1 cup	35.0	0.29	6	3.0	good
Spinach	1 cup	41.4	0.26	5	2.3	good
Summer Squash	1 cup	36.0	0.25	5	2.5	good
Cabbage	1 cup	43.5	0.23	5	1.9	good
Fennel	1 cup	27.0	0.20	4	2.7	good
Mustard Greens	1 cup	36.4	0.17	3	1.7	good
Tomatoes	1 cup	32.4	0.16	3	1.8	good
Sea Vegetables	1 TBS	10.8	0.16	3	5.3	good
Figs	1 medium	37.0	0.15	3	1.5	good
Romaine Lettuce	2 cups	16.0	0.13	3	2.9	good
Bok Choy	1 cup	20.4	0.13	3	2.3	good

World's Healthiest Foods Rating	Rule
excellent	DRI/DV>=75% OR Density>=7.6 AND DRI/DV>=10%
very good	DRI/DV>=50% OR Density>=3.4 AND DRI/DV>=5%
good	DRI/DV>=25% OR Density>=1.5 AND DRI/DV>=2.5%

Impact of Cooking, Storage and Processing

Pantothenic acid in foods does degrade over time. For example, in one study, fruit juice stored at room temperature for a week lost about 20% of its original pantothenic acid content. (We suspect that this vitamin might be a little more stable in a whole, unprocessed orange, but we were not able to find research in that area.) The Dutch military reported that canned emergency meals lost about 50% of pantothenic acid content after five years of storage. Needless to say, we don't recommend making

five-year-old foods a regular dietary staple—nor do we typically recommend canned foods when fresh foods are available. However, this research still provides some context for understanding the impact of storage on pantothenic acid.

Pantothenic acid is quite stable when it comes to cooking. This is especially true when foods are cooked at a neutral pH—for example, there is almost no loss of pantothenic acid in milk during pasteurization. Similarly, a study found that roasted beef retained about 90% of its initial pantothenic acid. (In the case of beef roasting, some kind of marinade or sauce would need to be used in order to alter the cooking pH.)

You will lose some pantothenic acid into cooking water when boiling. For example, we've seen evidence suggesting a moderate loss of pantothenic acid with quick boiled spinach. Cooking for longer will exaggerate this effect, providing a good reason to keep cooking times brief.

Risk of Dietary Deficiency

The only widely reported cases of pantothenic acid deficiency in humans that we are aware of were in grossly malnourished prisoners of war during World War II. Needless to say, this is a very specialized circumstance, and not the situation faced by the average U.S. adult.

With many other nutrients, we can build an experimental diet that depletes this nutrient to study the effects of deficiency. For pantothenic acid, however, because it is so ubiquitous in foods, researchers have not been able to build a diet low enough in the vitamin to cause visible clinical problems. This research situation provides further evidence that most diets are likely to provide sufficient amounts of this vitamin.

Because our recipes at World's Healthiest Foods contain fresh and whole foods, you should expect to not only meet a minimal standard for prevention of deficiency, but in fact to exceed your needs by a comfortable margin (which is fine, given that there is no known risk of toxicty from dietary intake of this nutrient).

Other Circumstances that Might Contribute to Deficiency

Outside of severe malnutrition—in which many nutrients are determined to be too low in a diet—we simply do not have research studies showing that pantothenic acid intake is too low due to certain lifestyle practices or other habits. For this reason, we suspect that most people who are getting sufficient amounts of food in their diet (including adequate amounts of calories) are also getting adequate amounts of pantothenic acid.

Relationship with Other Nutrients

As a member of the B complex, pantothenic acid metabolism—or at least the energy pathways in which it is active—will be disrupted by deficiency of other B vitamins. In particular, vitamin B12, folic acid, and biotin lend important support to pantothenic acid metabolism.

Risk of dietary Toxicity

There is no known risk of toxicity from dietary pantothenic acid. In research settings, use of supplemental pantothenic acid at daily doses more than 1000 times the Adequate Intake (AI) of 5 mg did not lead to any discernible side effects. For this reason, the National Academy of Sciences did not choose to establish a Tolerable Upper Intake Limit (UL) for pantothenic acid.

Disease Checklist

- High cholesterol
- Chronic fatigue
- Acne vulgaris
- Diabetes-related foot ulcers

Public Health Recommendations

The National Academy of Sciences (NAS) has established Dietary Recommended Intake Levels (DRIs) for pantothenic acid in the form of Adequate Intake (AI) amounts. These AI amounts are as follows:

- 0-6 months: 1.7 mg
- 6 months to 1 year: 1.8 mg
- 1-3 years: 2 mg
- 4-8 years: 3 mg
- 9-13 years: 4 mg
- 14+ years: 5 mg
- Pregnant women: 6 mg
- Lacatating women: 7 mg

Given the striking lack of toxicity demonstrated at even very high intakes of pantothenic acid, the National Academy of Sciences did not choose to establish a Tolerable Upper Intake Level (UL) for the vitamin. You can feel confident that you do not receive toxic amounts of pantothenic acid from your diet.

The Daily Value (DV) for pantothenic acid is set at 10 mg per 2000 calories in the diet. This is the value that you will see on food labels for pantothenic acid.

As our WHFoods daily recommended intake level for pantothenic acid, we chose the DRI for males and females 14 years and older of 5 milligrams.

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The World's Healthiest Foods

World's Healthiest Foods rich in phosphorus		
Food	Cals	DRI/DV
Scallops	126	69%
Sardines	189	64%
Soybeans	298	60%
Pumpkin Seeds	180	57%
Cod	96	56%
Tuna	147	54%
Salmon	158	52%
Lentils	230	51%
Shrimp	135	50%
Tempeh	222	41%

Basic Description

Phosphorus may be a lesser known mineral than the other minerals with which it is commonly grouped (like calcium or magnesium), but it is not one bit less important. Phosphorus is part of every human cell, most fluid balances throughout the body, core genetic processes (through its role as a component of RNA and DNA), and an extensive list of other processes central to our health.

Fortunately, very few nutrients are as widely available throughout our WHFoods as phosphorus. Not only do 75 of our foods rank as excellent, very good, or good sources of this mineral, but you can also find ranked sources of phosphorus in every single one of our food groups. In fact, it would be difficult to design a WHFoods-based diet that would meet your calorie needs yet somehow fail to provide you with the amount of phosphorus that you need.

In recent years, a good bit of controversy has unfolded about health risks involved with excessive dietary intake of phosphorus through increased consumption of soft drinks containing phosphoric acid and processed foods containing phosphate stabilizers, emulsifiers, anticaking agents, and acidity regulators. In our Summary of Food Sources and Risk of Dietary Toxicity sections, we will provide you with detailed information about this controversy. However, it is important to know that a meal plan based on whole natural foods rather than processed foods is likely to avoid excessive phosphorus risks.

Role in Health Support

Enable Basic Cell Function

Biologists who study the nature of living things typically regard the cell as the smallest functional unit of life. From single cell bacteria up through the tens of trillions of cells that make up our bodies, the structures of a cell are fairly consistent from organism to organism.

Perhaps the most defining characteristic of a cell is its outermost membrane, simply called the "cell membrane" (or sometimes the "plasma membrane"). The cell's outer membrane acts as a mediator between its internal space and everything that takes place outside of it. From a physiological and biochemical perspective, the cell membrane consists of a "phospholipid bilayer"—two rows of molecules composed primarily of fats (lipids) and phosphorus (in a special form called "phosphate" that involves a combination of phosphorus with oxygen and hydrogen). So as you can see, phosphorus is absolutely critical for the cell's very existence.

Phosphorus also floats around inside of every cell in a form referred to as a "phosphate anion." This form of phosphorus is similar to the form found in the cell membrane, and it is essential for a variety of different processes occurring inside of the cell.

Finally, with a few very notable exceptions, all cells contain a nucleus, and inside of the nucleus are genetic materials including RNA and DNA that both contain phosphorus in their chemical structure. In fact, phosphorus is sometimes referred to as the "glue" that holds DNA together.

So as you can see from its role in the cell's outer membrane, internal fluid, and genetic components, phosphorus is an essential part of the cell's design and it is a mineral that helps enable the cell's basic function.

Bone Support

Interestingly, despite its central role in cell function, most of the phosphorus in our body is not found in cell membranes, cell fluids, or genetic materials in the cell nucleus, but in our bones. At least in terms of weight, about 80-85% of this mineral is stored in bone. In fact, the main crystalline structure in bone, called hydroxyapatite, consists of phosphorus, calcium, oxygen, and hydrogen, and calcium and phosphorus are so important in formation of hydroxyapatite that it is often referred to as a "calcium phosphate" molecule. Hydroxyapatite is a key part of a bone's structural integrity.

So without phosphorus, your bone just wouldn't be as strong.

In addition to its role as a structural component, your dietary phosphorus can also play a couple other key roles in the complex metabolism of bone. First, dietary phosphorus can influence the production of bone by helping with phosphorylation—a chemical process by which phosphorus is linked to an amino acid—of signaling proteins that stimulate bone growth. This local hormone-like process is occurring all the time, balancing bone growth with breakdown and remodeling.

The other role is no less important, and has received much more attention of late. Dietary phosphorus is one of the key players in the hormonal process that controls calcium and bone metabolism. This hormonal process focuses on the activity of one particular hormone, called parathyroid hormone (PTH). High levels of phosphorus (as phosphate ions) in the blood increase the level of PTH. PTH then performs a number of actions all aimed at increasing calcium levels, including decreasing calcium loss in the urine, increasing calcium absorption from foods (indirectly, via activation of vitamin D), and pulling calcium from the bones.

It's that last effect—pulling calcium from the bones—that leaves some experts concerned that excessive dietary phosphorus could lead to problems with bone metabolism over time. Current evidence suggests that in extreme situations, like the dangerously high phosphorus levels seen in advanced kidney disease, elevated phosphates in the blood can change bone metabolism for the worse. In healthy people with normal kidney function, however, we don't have evidence to show heightened risk of this set of events.

Given the special relationship between phosphorus, calcium, hormonal function, and bone health, some observers have recommended a precise ratio of calcium-to-phosphorus intake in our everyday diet. Of course, a ratio of sorts is represented by the Dietary References Intakes (DRIs) that have been established by the National Academy of Sciences (NAS), since the adult calcium recommendations range from 800-1200 milligrams and the adult phosphorus recommendation is 700 milligrams. So we are talking about a ratio of approximately 1.1 - 1.7 in favor of calcium. However, we have yet to see research evidence to suggest that this ratio is needed for proper bone support. In fact, we have seen studies where the ratio of calcium to phosphorus also teeter-totters in favor of phosphorus without increased bone risks, except at levels where phosphorus intake exceeds calcium intake by a ratio greater than 2:1 simultaneous with calcium intake below the recommended daily amount. Taken as a whole, the research studies make it difficult for us to support any specific target ratio in dietary intake of calcium and phosphorus, and for this reason, we believe that balanced dietary intake of whole natural foods from a variety of different food groups is currently the best way to ensure a healthy ratio of these two mineral nutrients.

Maintaining Energy Supplies

When we consume foods and break apart food molecules through digestion and metabolism, one of our body's key goals is production of energy. In particular, different stages of food breakdown are designed to result in the production of a special energy carrying molecule called ATP (adenosine triphosphate). As the name of this molecule suggests, it contains three phosphorus atoms ("tri") in the form of phosphate groups. ATP is often referred to as a "universal energy carrier" because with a few exceptions, it can be used by virtually any type of cell and it can be used in a wide variety of different ways. Our cells are always making use of ATP to perform a wide variety of metabolic processes, and when ATP is being used, it can lose one or two of its phosphate groups to become ADP (adenosine diphosphate, where the "di" stands for "two") or AMP (adenosine monophosphate, where the "mono" stands for "one"). Most of our cells have specialized compartments, called mitochondria, in which these lower phosphate versions (AMP and ADP) can get charged back up into their highest phosphate form of ATP. As you can see, phosphorus is a mineral of central important in this energy supply process.

We have not seen research studies showing a direct relationship between ATP availability throughout the body and dietary intake of phosphorus. While we suspect that chronic severe deficiency of phosphorus could eventually compromise the availability of ATP, we know that the body would go to great lengths to try and avoid compromise in this energy carrying

system, by mobilizing phosphorus stored in bone and by taking other steps. But from a practical standpoint, eating a reasonably healthy diet with a reasonable number of phosphorus-rich foods should take care of any risk in this area.

Acid-Base Balance

In order for us to stay healthy, different parts of our body need to maintain very specific levels of acidity. In science terms, acidity level is referred to as pH. A conventional pH scale runs from 0 - 14, where "0" is defined as the most acidic level, "14" is defined as the least acidic (or most alkaline or basic) level, and "7" is defined as neutral. Since the pH of pure water is close to 7, and since our bodies are approximately 60% water, many of the pH levels in our body fall near the "7" level. In addition, many of the enzymes in our body are designed to work at this same pH level. The pH of our blood, for example, typically ranges from 7.35-7.45. The pH of our saliva usually ranges from 6.2 - 7.4. Only in very special places—like our stomach—does the pH level get quite low. (Prior to eating, the pH level in our stomach is usually 2.5 or below.) And there is no place in our body where pH shifts to its uppermost levels. In general, a simple summary of this pH information would be that it's extremely important for our body fluids to maintain their appropriate pH, and more often than not, appropriate pH falls somewhere near a neutral level of 7.0.

Phosphorus is one of the key nutrients our body uses to maintain proper pH. In fact, the phosphorus buffer system is one of the three major ways we balance pH in our body (the other systems being the bicarbonate and protein buffer systems). More specifically, when pH gets too low (the same as too acidic), hydrogen phosphate works to neutralize some of this acid, shifting pH back toward neutral. When pH gets too high (or too "basic"), dihydrogen phosphate works in the same way to pull pH back down toward balance. The fact that two closely-related phosphorus-containing compounds can have such opposite effects on pH doesn't necessarily seem to make sense on the surface. Regardless, luckily this process is occurring moment by moment throughout our body.

Like the role of dietary phosphorus in support of ATP, the role of dietary phosphorus in support of acid-base balance does not appear to require any special meal planning or food selection under most ordinary circumstances. (However, circumstances like end-stage kidney disease would be a different matter and might require special steps with phosphorus-containing foods.) When the National Academy of Sciences (NAS) determined the adult Dietary Reference Intake (DRI) for phosphorus of 700 milligrams, it did not do so based on observations about problematic pH balance at nearby intake levels. So as a general rule, believe that you can supply your body with the phosphorus it needs to maintain a healthy pH balance by eating a balanced variety of whole, natural foods that we profile on our website.

Summary of Food Sources

Since only three of our WHFoods rank as excellent sources of phosphorus (scallops, cod, and crimini mushrooms), we expect that most people will be getting their phosphorus primarily from our 28 very good and 44 good sources. That's 72 foods from which to choose, and you will find foods from every food group included in the list.

If we had to pick one food group as our top phosphorus source, it would be fish. Not only do all six of our WHFoods fish rank in our phosphorus top 10, but each one provides at least 300 milligrams of phosphorus per serving, or about 40% of the recommended daily amount. Meats, poultry, dairy, and eggs also tend to be rich in phosphorus. Our WHFoods in this group each contain about 100-250 milligrams of phosphorus per serving. In the U.S. as a whole, intake of these foods is relatively high, and for this reason they tend to account for a high percentage of total phosphorus intake. However, animal foods do not need to play a role in healthy phosphorus intake if you prefer to avoid them in your meal plan. The reason here is simple: numerous plant foods belonging to multiple food groups including vegetables, beans and legumes, nuts and seeds, and grains serve as good or very good sources of phosphorus.

We'd like to highlight some select plant foods that make sense to consider for optimal phosphorus nourishment. In the beans and legumes group, our list would include soybeans and lentils, with one serving of either food providing over half of the daily phosphorus requirement. In the nuts and seeds group, pumpkin seeds would be a standout, once again providing over half of the daily requirement in a single serving. Among the vegetables, green peas, broccoli, and spinach each provide about 100-150 milligrams per serving.

The phytic acid form of phosphorus found in many plant foods (and especially seeds, grains, beans, and legumes) has been a topic of widespread public discussion, centered mostly around the question of how extensively phytic acid binds together with minerals like calcium, iron, and zinc and lowers their absorption from the digestive tract up into the body. It is important to understand more about this form of phosphorus, however, than simply an assessment of its relationship to other nutrients.

Phytic acid (also referred to as inositol hexaphosphate, inositol hexakisphotphate, IP6, and phytate) is a widespread storage form for phosphorus in plants. Because appropriately timed availability of phosphorus is so essential in plant development,

special enzymes called phytases have evolved to help assure proper release of phosphorus from this special storage form. While human cells do not produce phytase enzymes, bacteria living in the human digestive tract can produce them, as can many other microorganisms (including many yeasts and fungi) as well as some animals.

Recent research suggests that the amount of phosphorus we get from phytic acid in plant foods depends on the health of our intestinal bacteria. This research has started to shift some conventional thinking about phytic acid in food, which has largely dismissed phytic acid as an undigestible form of phosphorus. However, some preliminary studies have speculated that complete breakdown of phytic acid is possible in the first segment of our large intestine (called the cecum) because this segment houses an unusual number of both aerobic and anaerobic bacteria (due to higher oxygen concentrations along the lining of the cecum than in other areas of the large intestine) and that a combination of aerobic-plus-anaerobic bacterial enzyme activities may be able release all of the phosphorus groups from phytic acid. Furthermore, preliminary research findings also suggest that populations of phytic acid-digesting bacteria might be able to adapt to an individual's diet over time and increase the availability of phosphorus from this storage form of the mineral.

Much more clearly documented is the fact that fermentation of foods (for example, fermentation of soybeans into tempeh) can increase phosphorus bioavailability from phytic acid, as can the action of yeast on phytic acid-containing grains ground into flour and used in bread making. So once again, we see a pathway in which the phytic acid storage form of phosphorus in plants might also be able to serve as an important phosphorus source in human diets.

Finally, we would note that the soaking of beans, legumes, grains, and seeds has been shown to result in partial breakdown of phytic acid, and in some cases, up to 50% of phytic acid might get broken down in this way.

Taken as a whole, the research above suggests that phytic acid should not be dismissed as an unavailable form of phosphorus in plant foods, and that future research should help us understand more about this unique plant form of phosphorus. Interestingly, the degree to which phytic acid binds minerals like calcium, iron, and zinc may also be related to the action of microorganisms on phytic acid, either during food production or inside of our digestive tract. However, we will address this issue a little further in our Relationship with Other Nutrients section.

Added phosphates make up a significant portion of the total phosphorus intake in the United States. We'll discuss where these are found in the next section. For now, understand that an average United States resident may eat more than their entire daily intake requirement from added phosphorus alone, and that this amount added during food processing has doubled over the past twenty years.

Introduction to Nutrient Rating System Chart

In order to better help you identify foods that feature a high concentration of nutrients for the calories they contain, we created a Food Rating System. This system allows us to highlight the foods that are especially rich in particular nutrients. The following chart shows the World's Healthiest Foods that are either an excellent, very good, or good source of phosphorus. Next to each food name, you'll find the serving size we used to calculate the food's nutrient composition, the calories contained in the serving, the amount of phosphorus contained in one serving size of the food, the percent Daily Value (DV%) that this amount represents, the nutrient density that we calculated for this food and nutrient, and the rating we established in our rating system. For most of our nutrient ratings, we adopted the government standards for food labeling that are found in the U.S. Food and Drug Administration's "Reference Values for Nutrition Labeling." Read more background information and details of our rating system.

World's Healthiest Foods ranked as quality sources of phosphorus						
Food	Serving Size	Cals	Amount (mg)	DRI/DV (%)	Nutrient Density	World's Healthiest Foods Rating
Scallops	4 oz	125.9	483.08	69	9.9	excellent
Cod	4 oz	96.4	391.22	56	10.4	excellent
Mushrooms, Crimini	1 cup	15.8	86.40	12	14.0	excellent
Sardines	3.20 oz	188.7	444.52	64	6.1	very good
Soybeans	1 cup	297.6	421.40	60	3.6	very good
Pumpkin Seeds	0.25 cup	180.3	397.64	57	5.7	very good
Tuna	4 oz	147.4	377.62	54	6.6	very good
Salmon	4 oz	157.6	365.14	52	6.0	very good
Lentils	1 cup	229.7	356.40	51	4.0	very good
Shrimp	4 oz	134.9	347.00	50	6.6	very good

Turkey	4 oz	166.7	260.82	37	4.0	very good
Chicken	4 oz	187.1	258.55	37	3.6	very good
Beef	4 oz	175.0	240.40	34	3.5	very good
Yogurt	1 cup	149.4	232.75	33	4.0	very good
Tofu	4 oz	164.4	215.46	31	3.4	very good
Oats	0.25 cup	151.7	203.97	29	3.5	very good
Green Peas	1 cup	115.7	161.17	23	3.6	very good
Broccoli	1 cup	54.6	104.52	15	4.9	very good
Cow's milk	4 oz	74.4	102.48	15	3.5	very good
Spinach	1 cup	41.4	100.80	14	6.3	very good
Asparagus	1 cup	39.6	97.20	14	6.3	very good
Brussels Sprouts	1 cup	56.2	87.36	12	4.0	very good
Summer Squash	1 cup	36.0	70.20	10	5.0	very good
Beet Greens	1 cup	38.9	59.04	8	3.9	very good
Mustard Greens	1 cup	36.4	58.80	8	4.2	very good
Swiss Chard	1 cup	35.0	57.75	8	4.2	very good
Bok Choy	1 cup	20.4	49.30	7	6.2	very good
Fennel	1 cup	27.0	43.50	6	4.1	very good
Tomatoes	1 cup	32.4	43.20	6	3.4	very good
Turnip Greens	1 cup	28.8	41.76	6	3.7	very good
Cauliflower	1 cup	28.5	39.68	6	3.6	very good
Tempeh	4 oz	222.3	286.90	41	3.3	good
Quinoa	0.75 cup	222.0	281.20	40	3.3	good
Garbanzo Beans	1 cup	269.0	275.52	39	2.6	good
Navy Beans	1 cup	254.8	262.08	37	2.6	good
Pinto Beans	1 cup	244.5	251.37	36	2.6	good
Kidney Beans	1 cup	224.8	244.26	35	2.8	good
Black Beans	1 cup	227.0	240.80	34	2.7	good
Cashews	0.25 cup	221.2	237.20	34	2.8	good
Sunflower Seeds	0.25 cup	204.4	231.00	33	2.9	good
Sesame Seeds	0.25 cup	206.3	226.44	32	2.8	good
Lima Beans	1 cup	216.2	208.68	30	2.5	good
Lamb	4 oz	310.4	204.12	29	1.7	good
Dried Peas	1 cup	231.3	194.04	28	2.2	good
Rye	0.33 cup	188.5	185.16	26	2.5	good
Millet	1 cup	207.1	174.00	25	2.2	good
Barley	0.33 cup	217.1	161.92	23	1.9	good
Brown Rice	1 cup	216.4	161.85	23	1.9	good
Cheese	1 oz	114.2	145.15	21	3.3	good
Peanuts	0.25 cup	206.9	137.24	20	1.7	good
Potatoes	1 cup	160.9	121.10	17	1.9	good
Buckwheat	1 cup	154.6	117.60	17	2.0	good
Almonds	0.25 cup	132.2	111.32	16	2.2	good
Sweet Potato	1 cup	180.0	108.00	15	1.5	good
Flaxseeds	2 TBS	74.8	89.88	13	3.1	good
Eggs	1 each	77.5	86.00	12	2.9	good
Onions	1 cup	92.4	73.50	11	2.0	good
Beets	1 cup	74.8	64.60	9	2.2	good
Collard Greens	1 cup	62.7	60.80	9	2.5	good
Corn	1 each	73.9	59.29	8	2.1	good
Cabbage	1 cup	43.5	49.50	7	2.9	good
Carrots	1 cup	50.0	42.70	6	2.2	good

Kale	1 cup	36.4	36.40	5	2.6	good
Green Beans	1 cup	43.8	36.25	5	2.1	good
Strawberries	1 cup	46.1	34.56	5	1.9	good
Mustard Seeds	2 tsp	20.3	33.12	5	4.2	good
Romaine Lettuce	2 cups	16.0	28.20	4	4.5	good
Garlic	6 cloves	26.8	27.54	4	2.6	good
Miso	1 TBS	34.2	27.33	4	2.1	good
Cucumber	1 cup	15.6	24.96	4	4.1	good
Celery	1 cup	16.2	24.24	3	3.9	good
Bell Peppers	1 cup	28.5	23.92	3	2.2	good
Soy Sauce	1 TBS	10.8	23.40	3	5.6	good
Cumin	2 tsp	15.8	20.96	3	3.4	good
Sea Vegetables	1 TBS	10.8	18.05	3	4.3	good
Parsley	0.50 cup	10.9	17.63	3	4.1	good

World's Healthiest Foods Rating	Rule
excellent	DRI/DV>=75% OR Density>=7.6 AND DRI/DV>=10%
very good	DRI/DV>=50% OR Density>=3.4 AND DRI/DV>=5%
good	DRI/DV>=25% OR Density>=1.5 AND DRI/DV>=2.5%

Impact of Cooking, Storage and Processing

Phosphorus, like other minerals, is quite stable to storage, and is not destroyed or created as foods sit on the shelf. Sometimes, as we'll get to in a second, foods that are meant to be stored for long periods will have added phosphorus to help preserve them. As for whole, natural foods, you will find our recommendations for best ways to store each individual food in the How to Select and Store section found in each food's individual website profile.

As explained in a good bit of detail earlier, many plant foods store up a significant amount of phosphorus in the form of phytic acid, and there are certain preparation steps that can increase the availability of phosphorus from this food form. While these preparation steps could potentially be applied to grains, nuts, and seeds as well as beans and legumes, most studies have focused on dried beans. If dried beans are soaked overnight prior to cooking the next day, about half of their phytic acid can be broken down through this soaking process. We do not believe that this step is important for your phosphorus nourishment. At the same time, we also have not seen any research to suggest that you should avoid soaking beans.

The sprouting of beans (or grains or nuts or seeds) prior to cooking also appears to result in breakdown of phytic acid by as much as 50% or more. Of course, sprouting is a process that has an impact on many other molecules besides phytic acid, and many people report better digestion of sprouted foods. As a stage in the development of seeds into a mature plants, sprouts can also be an unusually concentrated food form for many nutrients. Once again, we do not believe that the sprouting of beans or other foods is required for good phosphorus nourishment. At the same time, we know that sprouted foods are commonly eaten and enjoyed by many people, and are well-researched with respect to their nutrient richness. As described earlier, phosphorus is a common food additive in the form of stabilizers, emulsifiers, anticaking agents, and acidity regulators. Below is a brief list of some food additive forms of this mineral.

- Sodium Phosphate
- Calcium Phosphate
- Dicalcium Phosphate
- Tricalcium Phosphate
- Pyrophosphate
- Sodium Pyrophosphate
- Sodium Aluminum Phosphate
- Phosphoric Acid

Some foods often containing significant amounts of added phosphates include lunch meats, ham, sausages, canned fish, baked goods (including baked cookies and bars), baking mixes (like cake and pancake mix), yogurts, cheeses, and soft drinks. Frozen

patties, nuggets, and strips made from breaded chicken and other meats can also contain significant amounts of these additives. In the U.S., persons relying on processed foods similar to the list of foods above may obtain over half of their daily phosphorus intake from these additives.

Soft drinks (meaning carbonated cola-type beverages) are processed beverages of special concern in terms of phosphorus because many contain added phosphoric acid in amounts of 400-600 milligrams per can or bottle. (While phosphates are classified as salts of phosphoric acid in technical chemical terms, these two terms are used interchangeably in most practical discussions of phosphorus-based food additives.) As you can see, the amount of phosphoric acid in a single soda can easily exceed over half of the daily requirement for phosphorus, and persons consuming several such sodas each day would exceed the daily requirement from the sodas alone. As described earlier, the significance of routine intake of phosphorus additives is not entirely clear in current research studies. While we would expect to see great imbalances in calcium-to-phosphorus ratio affecting bone health and the health of other body systems, research findings in this area are somewhat mixed and do not lend themselves to simple conclusions. We will talk more about this added phosphorus issue in our Risk of Dietary Toxicity section.

Risk of Dietary Deficiency

The risk of phosphorus deficiency in the United States is very low. In fact, dietary survey data show that average U.S. adult men eat more than twice the amount of phosphorus that they need each day. Women average 170% of the Dietary Reference Intake (DRI) level. In fact, according to the NHANES 2009-2010 data from the study, "What We Eat in America," most age and gender groups averaged higher than the phosphorus DRI. (Two groups that averaged slightly below the DRI were females 6-11 and 12-19, and we will provide more information about these groups in the next section of this article.) Given the availability of phosphorus-rich foods from every food group, and the very large number of whole, natural foods containing significant amounts of phosphorus, we just don't expect phosphorus deficiency to be a problem in balanced diets based on whole, natural foods.

The need for phosphorus can be greatest at times of greatest bone growth, as typically begins in late childhood and adolescence. Interestingly, this bone connection means that the phosphorus DRI for 9-18 year olds is higher than the DRI for adults 19 and older. This developmentally increased need for phosphorus means that teenagers might need to pay special attention to intake of this nutrient, and in particular, teenage girls, since males average greater intake of phosphorus than females across the age spectrum. NHANES study data from 2009-2010 showed that boys 6-11 years and 12-19 years averaged above the phosphorus DRI. However, this same study data showed that girls 6-11 only averaged 96% of the DRI, with girls 12-19 averaging 95%. So it is easy to see the possible challenge of meeting phosphorus needs during times of rapid bone growth. While it is true that some teenagers can be especially prone to increased intake of processed foods that are likely to contain food additive forms of phosphorus, special attention to this mineral might still be especially important for teenagers following meal plans that are based on whole, natural foods. And in addition, we continue to believe that meal plans based on whole, natural foods provide the greatest health benefits for all age groups.

Other Circumstances that Might Contribute to Deficiency

Because it is such an important component in bone growth, phosphorus needs are usually greatest during the late childhood and adolescent years. (As mentioned earlier, the DRI for 9-18 year olds is 1,250 milligrams, in comparison to 700 milligrams for persons 19 and older.) Since bone growth clearly contributes to the need for increased phosphorus, period of time involving rapid bone growth can pose greater deficiency risk. And as described earlier, while average intake of phosphorus among males 6-18 years exceeded the DRI level, average intake for girls 6-18 only reaches 95-96% of the DRI. While this percentage is very close to 100%, and while intake of processed food containing added phosphates could greatly increase this percentage, we still believe that this developmental period is a time when intake of phosphorus might call for special attention, particularly in a meal plan focused on whole, natural foods. The ways that we regulate phosphorus and calcium concentrations in the body are complex, and involve the kidney, the lungs, and a number of hormones. Disease-based disruptions in any of these factors can create imbalances in acid-base balance that can have serious consequences. Special diets that manage phosphorus intake upward or downward from usual intake levels may be required in the presence of chronic health problems that involve compromise to lung or kidney function, or in the case of diagnosed hormonal problems that can affect blood calcium levels.

Relationship with Other Nutrients

The relationship between calcium and phosphorus is complex and important. The same hormones and kidney compensatory measures that regulate calcium levels also tend to affect phosphorus nutrition. Also, large amounts of dietary calcium can impair absorption of dietary phosphorus.

In our Healthiest Way of Eating Plan—composed almost exclusively of WHFoods using WHFoods recipes—we averaged 1,326 milligrams of daily calcium and 1,716 milligrams of daily phosphorus, or a ratio slightly in favor of phosphorus at 1.3:1. However, a person eating no WHFoods fish (which all provide about 350 milligrams of phosphorus or more per serving) and strong intake of tofu and green vegetables (averaging over 150 milligrams of dietary calcium per serving) could easily tip the balance in favor of calcium. And to add in a third comparison, the 19-70 adult male DRI requirements of 800 milligrams for calcium and 700 milligrams for phosphorus would result in a ratio of 1.1 in favor of calcium, while the 19-50 adult female requirements of 1,000 milligrams for calcium and 700 milligrams for phosphorus would result in a ratio of 1.4:1 calcium-phosphorus ratio. So as you can see, the notion of a generalized "ideal" calcium-to-phosphorus ratio does not make much sense. One thing we would say about dietary balances between calcium and phosphorus from whole, natural foods is that they seldom get extremely lop-sided in one direction or the other. While a single food—for example collard greens, with 267 milligrams of calcium per WHFoods serving and 60 milligrams of phosphorus—could contain a ratio much greater than 2:1, it is somewhat unusual for a balanced, natural, whole foods meal plan to go much further than 2:1 or so in either direction. We have not seen a balanced, natural, whole foods diet that contained tripled the amount of calcium as phosphorus or vice-versa.

As a general recommendation, we encourage consumption of a natural, whole foods meal plan that feels best matched to your own food preferences and health needs, and to let the calcium-to-phosphorus ratio take whatever form that meal plan naturally brings along with it.

Because phytic acid is a form of phosphorus that can bind certain minerals (called divalent cations) including calcium, iron, and zinc, there has been debate over the relationship between phosphorus intake (in the form of phytic acid) and absorption of these other minerals. As described earlier, we have not seen evidence for increased risk of calcium, iron, or zinc deficiency based on intake of phytic acid from whole, natural foods in a balanced meal plan. Also, as described earlier, recent research suggests that breakdown of phytic acid routinely occurs in the large intestine due to enzymatic activity of intestinal bacteria. This research should eventually provide us with more information about absorption of other minerals that might become bound to phytic acid. Of special interest in this area is the potential relationship between phytic acid intake, calcium absorption, and bone health. We've seen several studies in this area showing no negative impact of higher phytic acid whole foods on bone calcium status even when total phosphorus intake reached the 3,000 milligram level, provided that calcium intake stayed relatively high (at approximately 2,000 milligrams). In other words, a calcium:phosphorus ratio of 0.66 from whole, natural foods was not found to compromise bone calcium status. However, we are not sure that this same welcomed finding would hold true for excessive amounts of phosphorus provided in the form of phosphate additives in a processed diet. This concern is one of the many reasons we always prefer whole foods over processed versions.

Risk of dietary Toxicity

The risk of toxicity from excessive phosphorus is real, and this is one of a relatively small number of nutrients that U.S. residents frequently eat in excess of recommended amounts. The National Academy of Sciences established a Tolerable Upper Intake Limit (UL) of 4000 mg per day for adolescents and adults. The stricter recommendation for children 1-8 years and adults over 70 years of age is 3,000 milligrams, and for pregnant women the recommendation is 3,500 milligrams. As mentioned earlier, while these amounts might sound generous, it is easy to obtain 1,000 milligrams of phosphoric acid from two cans of soda pop.

The risk associated with excessive dietary phosphorus tends to show up in changes to calcium metabolism. Part of the problem is due to calcium loss, either from the bone or due to reduction in absorption from the intestine. Almost paradoxically, we also see diets too high in phosphorus leading to deposition of calcium in tissues where it doesn't belong, like arteries and kidneys. The reason we see calcium metabolism take this hit is because excessive phosphorus can disturb the tight control of electrolyte levels, leading to changes in the complex hormone balance that regulates the movement of calcium through our bodies.

Note that the problems we see with excess phosphorus intake do not show up immediately, but instead unfold over a long period of time. Parallel to diets too high in sodium or cholesterol, there is a "silent" underlying damage over time that only becomes apparent when things have gotten more severe. So it is a good idea to think about excess phosphorus intake as a potential health risk regardless of your stage of life.

In particular, however, older adults may be more susceptible to detrimental effects of excessive phosphorus. This is because kidney function, even in people without kidney disease, tends to decline with age. As mentioned earlier, this greater susceptibility translates into a UL of 3,000 milligrams for persons over 70 years of age. Also, pregnant women may want to be more careful about dietary phosphorus. This is because pregnancy increases absorption of phosphorus from foods substantially over what it is in a non-pregnant state. Once again, this extra caution translates into a pregnancy UL of 3,500 milligrams.

The good news is that it would be relatively difficult in any age group, although not impossible, to routinely exceed the UL for phosphorus from fresh, natural, unprocessed foods alone. The added phosphorus in foods—phosphates are used as

preservatives and flavorings—are often where much of the excess risk comes from. Note that the World's Healthiest Foods recipes will contain almost no added phosphates of any kind. As such, we believe that the closer you stick to our whole and fresh foods cooking strategies, the less likely you'll be to push too hard on phosphorus at the expense of other minerals.

There will be some people whose diets are so high in calories that they will exceed the UL even without added phosphates. For instance, many endurance athletes will routinely eat as many as 6000 calories in a single day. The DRI document clarifies that the UL is not meant to fit this contingency, and that as long as other minerals are similarly well represented, high calorie diets do not present risk related to phosphorus intake.

Disease Checklist

- Kidney disease
- Cardiovascular prevention
- Osteoporosis risk

Public Health Recommendations

In 1997, the National Academy of Sciences (NAS) released its Dietary Reference Intake (DRI) recommendations for phosphorus. All DRI recommendations came in the form of Recommended Dietary Allowances (RDAs), except for DRI recommendations involving infants under one year of age. The infant DRIs came in the form of Adequate Intake (AI) levels. The phosphorus DRIs are as follows.

- 0-6 months: 100 mg
- 6 months-1 year: 275 mg
- 1-3 years: 460 mg
- 4-8 years: 500 mg
- 9-18 years: 1250 mg
- 19+ years: 700 mg
- Pregnant and lactating women: Same as recommendations by age

The DRIs also established Tolerable Upper Intake Levels (UL) for phosphorus. These ULs are summarized below.

- 0-1 year: No UL
- 1-8 years: 3000 mg
- 9-70 years: 4000 mg
- 70+ years: 3000 mg
- Pregnant women: 3500 mg
- Lactating women: 4000 mg

The Daily Value (DV) for phosphorus is 1000 mg. This is the amount that you'll see on food labels.

As our standard at WHFoods, we chose the adult DRI of 700 milligrams of daily phosphorus intake.

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The World's Healthiest Foods

World's Healthiest Foods rich in potassium		
Food	Cals	DRI/DV
Beet Greens	39	37%
Lima Beans	216	27%
Swiss Chard	35	27%
Sweet Potato	180	27%
Potatoes	161	26%
Soybeans	298	25%
Spinach	41	24%
Avocado	240	21%
Pinto Beans	245	21%
Lentils	230	21%

Basic Description

Potassium is a mineral found in varying amounts in almost all foods. Vegetables, especially green leafy varieties, are generally our richest sources of potassium.

We list three excellent sources of potassium, 16 as very good sources, and 39 as good sources by our Nutrient Rating System. In other words, over half of our WHFoods provide you with significant amounts of potassium! In fact, all of our WHFoods contain at least some small but measurable amount of this mineral.

Along with sodium, chloride, calcium, and magnesium, potassium is an electrolyte, meaning that it helps to conduct electrical charges in the body. Like all the other electrolytes, our bodies have evolved elaborate systems to control blood levels in a narrow range. This is good news since normal levels of potassium are absolutely critical to life—if potassium levels get too high or too low, the heart and nervous system completely shut down. Luckily, most of us are able to obtain enough potassium from foods to meet our most basic needs. But since just meeting a minimal intake need is not a recipe for health, many people in the United States often fail to obtain optimal amounts of this nutrient, and pay a health cost for it.

This is because Americans fail to regularly eat fresh fruits and vegetables, while eating heavily salted prepared foods. In fact, a recent survey suggests that only about 5% of Americans meet minimal goals for eating fruits and vegetables. If you do not regularly meet these goals, it will be difficult to ensure your potassium intake will be optimal.

It is impossible to understand the role of potassium without addressing sodium as well. Sodium and potassium exist in a partnership, and each important use of potassium requires sodium to maintain balance. Importantly, as average diets in the United States have become depleted in potassium, they have become much more concentated in sodium.

For example, a heavily salted commercial tomato juice—despite containing a potassium rich food like tomato—often contains a ratio of sodium to potassium of more than 2:1. This ratio is not a desirable one! By comparison, our Mushroom, Tomato, and Basil Frittata has a ratio of sodium to potassium of 1:3, a much more health-promoting pattern. In fact, we believe one of the central benefits of the World's Healthiest Foods approach is the way it rebalances sodium and potassium in a manner that is more consistent with good heart and kidney health.

Role in Health Support

Maintaining Normal Blood Pressure

Diets high in potassium are associated with improved blood pressure control. There are several mechanisms contributing to this beneficial effect, including improved kidney function, reduction in blood clotting, and more efficient opening of blood vessels. Because of these important benefits, therapeutic diets aimed at improving blood pressure control often place primary focus on increasing potassium from foods.

A good example of how foods rich in potassium can decrease elevated blood pressure is seen in the DASH (Dietary Approaches to Stop Hypertension) diet trials, where participants with high blood pressure who consumed an average of 8 to 10 total servings of fresh fruits and vegetables per day experienced significant drops in their blood pressure level. These servings focused on whole food choices similar to those featured in our recipes and the diet avoided processed and salt-choked choices like French fries. One key factor in these blood pressure benefits was the healthy balance of potassium to other minerals in these fresh fruits and vegetables.

Kidney Health

Perhaps the most important way to ensure strong kidney health is to keep your blood pressure under good control. As discussed above, diets high in potassium are well known to help with this.

In addition, diets rich in potassium have been associated with a reduction in kidney stone risk. This is thought to be because the naturally occurring potassium salts in plant foods help to neutralize acidity in the blood stream. This prevents leeching of calcium from the bones to buffer the acid, which in turn reduces urine calcium, preventing its deposition in the form of a stone. Please note that while diets rich in potassium can be helpful in preventing certain kidney-related problems in a healthy people with good kidney function, persons already known to have kidney problems and who are diagnosed with certain diseases of the kidney may need to carefully regulate their intake of potassium, since their kidneys might not otherwise be able to regulate the levels of potassium in their bloodstream.

Summary of Food Sources

Probably the first food that comes to mind when thinking about potassium is the banana. This is not wrong—by our Rating System, bananas are a good source of potassium. But there are 32 foods on our Rating Chart with more potassium per calorie than the banana.

Speaking more generally, the most potassium-rich food sources of potassium are fruits and vegetables. Some legumes, fish, and dairy products can also make important contributions to our daily potassium intake; yet, because these foods have more calories, they are not as highly rated by our Nutrient Richness System. For example, Swiss chard and lima beans both contain nearly 1000 milligrams of potassium, but because a serving of lima beans contains six times as many calories than a serving of chard, the nutrient richness of the chard is higher.

Potassium content within the group of fruits and vegetables can vary widely, even between two foods that seem superficially very similar. For example, a cup of cooked Swiss chard contains more than three times as much potassium as the same amount of kale or mustard greens.

Even with this relatively wide variation, you should feel confident that a largely plant-based diet like the World's Healthiest Foods plan will meet your potassium needs quite readily. In fact, our 7-day meal plan example averages nearly 50% more than the Daily Value (DV) standard for potassium.

Many of our recipes, like this one for Broiled Chicken and this one for Poached Eggs Over Spinach and Mushrooms contain more than half of our recommended daily intake value for potassium. The first of these two recipes contains more potassium than the average adult American woman eats in a single day.

Introduction to Nutrient Rating System Chart

In order to better help you identify foods that feature a high concentration of nutrients for the calories they contain, we created a Food Rating System. This system allows us to highlight the foods that are especially rich in particular nutrients. The following chart shows the World's Healthiest Foods that are either an excellent, very good, or good source of potassium. Next to each food name, you'll find the serving size we used to calculate the food's nutrient composition, the calories contained in the serving, the amount of potassium contained in one serving size of the food, the percent Daily Value (DV%) that this amount represents, the nutrient density that we calculated for this food and nutrient, and the rating we established in our rating system. For most of our nutrient ratings, we adopted the government standards for food labeling that are found in the U.S. Food and Drug Administration's "Reference Values for Nutrition Labeling." Read more background information and details of our rating system.

World's Healthiest Foods ranked as quality sources of potassium						
	Serving		Amount	DRI/DV	Nutrient	World's Healthiest

Food	Size	Cals	(mg)	(%)	Density	Foods Rating
Beet Greens	1 cup	38.9	1308.96	37	17.3	excellent
Swiss Chard	1 cup	35.0	960.75	27	14.1	excellent
Spinach	1 cup	41.4	838.80	24	10.4	excellent
Bok Choy	1 cup	20.4	630.70	18	15.9	excellent
Beets	1 cup	74.8	518.50	15	3.6	very good
Brussels Sprouts	1 cup	56.2	494.52	14	4.5	very good
Broccoli	1 cup	54.6	457.08	13	4.3	very good
Cantaloupe	1 cup	54.4	427.20	12	4.0	very good
Tomatoes	1 cup	32.4	426.60	12	6.8	very good
Asparagus	1 cup	39.6	403.20	12	5.2	very good
Cabbage	1 cup	43.5	393.00	11	4.6	very good
Carrots	1 cup	50.0	390.40	11	4.0	very good
Fennel	1 cup	27.0	360.18	10	6.9	very good
Summer Squash	1 cup	36.0	345.60	10	4.9	very good
Mushrooms, Crimini	1 cup	15.8	322.56	9	10.5	very good
Kale	1 cup	36.4	296.40	8	4.2	very good
Turnip Greens	1 cup	28.8	292.32	8	5.2	very good
Celery	1 cup	16.2	262.60	8	8.4	very good
Romaine Lettuce	2 cups	16.0	232.18	7	7.5	very good
Bell Peppers	1 cup	28.5	194.12	6	3.5	very good
Lima Beans	1 cup	216.2	955.04	27	2.3	good
Sweet Potato	1 cup	180.0	950.00	27	2.7	good
Potatoes	1 cup	160.9	925.55	26	3.0	good
Soybeans	1 cup	297.6	885.80	25	1.5	good
Pinto Beans	1 cup	244.5	745.56	21	1.6	good
Lentils	1 cup	229.7	730.62	21	1.6	good
Avocado	1 cup	240.0	727.50	21	1.6	good
Kidney Beans	1 cup	224.8	716.85	20	1.6	good
Dried Peas	1 cup	231.3	709.52	20	1.6	good
Tuna	4 oz	147.4	597.61	17	2.1	good
Papaya	1 medium	118.7	502.32	14	2.2	good
Winter Squash	1 cup	75.8	494.05	14	3.3	good
Salmon	4 oz	157.6	492.15	14	1.6	good
Banana	1 medium	105.0	422.44	12	2.1	good
Green Peas	1 cup	115.7	373.30	11	1.7	good
Scallops	4 oz	125.9	356.07	10	1.5	good
Onions	1 cup	92.4	348.60	10	1.9	good
Cod	4 oz	96.4	327.72	9	1.7	good
Oranges	1 medium	61.6	237.11	7	2.0	good
Mustard Greens	1 cup	36.4	226.80	6	3.2	good
Collard Greens	1 cup	62.7	222.30	6	1.8	good
Strawberries	1 cup	46.1	220.32	6	2.5	good
Kiwifruit	1 2 inches	42.1	215.28	6	2.6	good
Raspberries	1 cup	64.0	185.73	5	1.5	good
Green Beans	1 cup	43.8	182.50	5	2.1	good
Grapefruit	0.50 medium	41.0	177.92	5	2.2	good
Cauliflower	1 cup	28.5	176.08	5	3.2	good
Watermelon	1 cup	45.6	170.24	5	1.9	good
Parsley	0.50 cup	10.9	168.42	5	7.9	good
Cucumber	1 cup	15.6	152.88	4	5.0	good
Eggplant	1 cup	34.6	121.77	3	1.8	good

Figs	1 medium	37.0	116.00	3	1.6	good
Turmeric	2 tsp	15.6	111.10	3	3.7	good
Sea Vegetables	1 TBS	10.8	110.96	3	5.3	good
Chili Peppers	2 tsp	15.2	105.30	3	3.6	good
Plum	1 2-1/8 inches	30.4	103.62	3	1.8	good
Apricot	1 whole	16.8	90.65	3	2.8	good

World's Healthiest Foods Rating	Rule
excellent	DRI/DV>=75% OR Density>=7.6 AND DRI/DV>=10%
very good	DRI/DV>=50% OR Density>=3.4 AND DRI/DV>=5%
good	DRI/DV>=25% OR Density>=1.5 AND DRI/DV>=2.5%

Impact of Cooking, Storage and Processing

Like other minerals, potassium is stable to storage. There are not significant changes to the bioavailability of potassium over the storage life of any important food. You do not need to take any special storage precautions to maintain the potassium content of your foods.

Cooking vegetables can lead to loss of some or much of their potassium content. If you follow our recipes carefully, however, enough potassium will be preserved to provide you with health benefits. For example, lightly boiling spinach in the way we describe in our spinach profile leads to a loss of about one-third of the total potassium; yet, as you see from the chart below, cooked spinach still features more than 800 milligrams of potassium—over 20% of the Daily Value (DV).

The key to preserving potassium content of food during cooking is to minimize duration of contact of that food with cooking water. For instance, boiling spinach for a second minute increases the loss of potassium to up to 72% of its initial content. The World's Healthiest Foods cooking methodology is designed to minimize mineral losses, so we recommend you pay close attention to cooking times to ensure good potassium retention in your foods.

It is not uncommon to find added potassium compounds in processed food. Examples include potassium sorbate added to foods as a preservative and mold inhibitor; potassium bisulfite added as a preservative; potassium chloride as a salt replacer; potassium bitartrate as a flavor modifier; and dipotassium phosphate as a stabilizer and de-acidifier. In many cases, the addition of potassium during processing does not add large amounts to average daily potassium intake. However, in the case of processed products like salt substitutes, the addition of potassium can be substantial. Some salt substitute brands using potassium chloride provide over 600 milligrams of potassium in one-quarter teaspoon.

Risk of Dietary Deficiency

We usually use the Dietary Reference Intake (DRI) standards from the National Academy of Sciences (NAS) when setting our own nutrient recommendations. One subcategory of DRIs are the Adequate Intakes, or AI standards. Based on these AIs, more than 98% of all Americans fail to get enough potassium on a daily basis. With other nutrients, we usually focus on ages, gender, or disease conditions as special risk categories for deficiency. When we discuss potassium, though, virtually *everybody* is at risk for deficiency.

Although all groups appear to be doing poorly, women and African-Americans appear to have the lowest potassium intake. The high risk of deficiency in Americans is directly related to our over-reliance on heavily processed foods as our main calorie sources. Whole foods meals like the recipes we feature here on the World's Healthiest Foods site should help to ensure low risk of potassium deficiency. Here is an example of a 10-minute recipe—Mediterranean-Style Salad—that contains nearly half of the daily recommended intake value for potassium.

Other Circumstances that Might Contribute to Deficiency

Even in people who get plenty of potassium, fluid loss can lead to problematic loss of potassium. For instance, people undergoing heavy physical training or who work outdoors on a hot day can run into this problem.

A more common reason to see low potassium levels is in people suffering from acute or chronic diarrhea. People with ongoing gastrointestinal illness may need to be careful to maintain normal potassium levels.

Use of certain prescription and over-the-counter medications can also increase risk of potassium deficiency.

Relationship with Other Nutrients

As mentioned above, the relationship between potassium and sodium is critical to the health benefits of diets high in potassium. The ratio of sodium to potassium in a modern, processed food diet is likely to be close to 5:1, with five times as much sodium as potassium. The U.S. would be a good example of an industrialized country with this type of high sodium:potassium ratio from processed foods. In non-industrialized countries where foraging and hunting determine the nature of the food supply, this ratio can be completely reversed, with five times as much potassium as sodium. Communities in some parts of Tanzania would be a good example of this type of hunter-gatherer culture.

Researchers do not know the exact best ratio of potassium to sodium in a meal plan. But they do know that the average U.S. diet is tilted way too far in the direction of sodium and not nearly enough toward potassium.

As a general rule of thumb, cheeses, breads, canned soups, and fast foods would be foods with much more sodium than potassium. Fruits, vegetables, and non-cheese dairy products should all contain more potassium than sodium.

Food	Potassium (mg)	Sodium (mg)	Sodium:Potassium Ratio
Banana	422	1	0.002
Summer squash	g296	3	0.01
Crimini mushrooms	389	5	0.01
Spinach	839	126	0.15
Yogurt	573	175	0.3
Sardines	360	458	1.3
Fast food cheeseburger	375	1137	3.0

As the above chart should make clear, fresh and whole foods tend to have more potassium than sodium, while prepared foods tend to feature the opposite ratio. Because the World's Healthiest Foods recipes tend to feature little to no added sodium, we are able to preserve this beneficial balance of sodium and potassium throughout our approach.

Some, but not all, research suggests that a diet rich in potassium may help to prevent loss of calcium in the urine. The idea here is that potassium salts found in fruits and vegetables tend to counter the effects of diets high in acid-forming proteins and that this in turn reduces the need to pull calcium from the bones to buffer the acid. To date, researchers have shown short-term benefits of dietary potassium on measures of calcium balance but have not been able to demonstrate improved bone health.

Risk of dietary Toxicity

For healthy people with normal kidney function, there is not any known risk of toxicity from excessive dietary potassium under any circumstance. People with conditions affecting fluid balance—including kidney disease, some hormonal conditions, and heart failure—should work with their doctor before deliberately trying to increase their dietary potassium.

It's also worth noting here that the National Academy of Sciences (NAS) has chosen not to set a Tolerable Upper Limit (UL) for potassium.

Disease Checklist

- High blood pressure
- Stroke
- Kidney stones
- Fatigue
- PMS
- Diarrhea
- Vomiting

- Endurance exercise

Public Health Recommendations

In 2004, the National Academy of Sciences (NAS) set Dietary Reference Intake (DRI) levels for potassium. Specifically, these levels were Adequate Intake (AI) levels for different age and gender groups as follows:

- 0-6 months: 400 mg
- 7-12 months: 700 mg
- 1-3 years: 3,000 mg
- 4-8 years: 3,800 mg
- 9-13 years: 4,500 mg
- 19+ years: 4,700 mg
- Pregnant women: 4,700 mg
- Lactating women: 5,100 mg

The Daily Value (DV) for potassium is 3,500 milligrams. This DV is the standard that you will see on food labels. It is also the standard that we adopted as our WHFoods standard.

There is currently no Tolerable Upper Intake Level (UL) for potassium.

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The World's Healthiest Foods

World's Healthiest Foods rich in protein		
Food	Cals	DRI/DV
Chicken	187	70%
Turkey	167	68%
Tuna	147	66%
Soybeans	298	57%
Salmon	158	53%
Beef	175	52%
Shrimp	135	52%
Lamb	310	51%
Scallops	126	47%
Sardines	189	45%

Basic Description

Protein may be the best-recognized of all nutrients in terms of its health importance.

Public health recommendations in the U.S. have included an emphasis on dietary protein for over a century! The very name of this nutrient comes from the Latin word *protos* meaning "first," and that meaning is consistent with the approach of many researchers who have long considered protein to be a nutrient "of first importance." However, even though the importance of protein is so deeply-rooted in nutritional science, researchers may actually be in the early stages of understanding the full health benefits provided by this remarkable nutrient. The reason involves the surprising number of roles that protein plays in our body. Consider the following summary of basic functions played by protein in our everyday health.

Body System	Function	Examples of Proteins Involved
Digestive	serves as digestive enzymes	amylases, chymotrypsin, disaccharides, lipases, peptidases, proteases, ribonucleases
Connective tissue (and extracellular fluid)	provide elasticity, provide fluid gel structures, allow for adhesiveness	amylases, chymotrypsin, disaccharides, lipases, peptidases, proteases, ribonucleases
Muscle	provide components that allow for contraction	actin, myosin, troponin, tropomysin, vinculin
Endocrine	serve as hormones	insulin, growth hormone, thyroid stimulating hormone (TSH), follicle stimulating hormone (FSH)
Nervous	provide amino acids for neurotransmitters	epinephrine, norepinephrine, serotonin, melatonin
Genetic	formation of DNA and RNA	histones, nucleic acid polymerizing enzymes
Cardiovascular	maintain correct blood pressure and transport a variety of substances	albumin, alpha-globulin, beta-globulin, fibronectin, Complement A
Cellular	provide structural integrity and protection	actin, tubulin, spectrin, intermediary filaments
Signaling	transfer chemical messages into and out of cells	GCPRs (G-protein coupled receptors)
Energy production	promote oxygen-based energy production inside of mitochondria	ATP synthetase, NADH reductase, succinate dehydrogenase
Detoxification	processing potential toxins to enable elimination from the body	cytochrome P450 enzymes, sulfotransferase enzymes, methyltransferase enzymes

As you can see, there are few bodily processes that don't rely on protein in some shape or form!

Luckily, it is not difficult to find foods that contain protein. Half of our WHFoods serve as good, very good, or excellent sources of this nutrient. In addition, all but one of our WHFoods (the single exception is extra virgin olive oil) provide a measurable amount of protein. In addition to this wide-ranging availability of protein, you can pick a relatively small number of foods and reach the Daily Value (DV) for protein—50 grams—fairly easily. For example, four ounces of cod, four ounces of tofu, and 1.5 cups of green peas will give you the full 50 grams. However, we do not recommend that you select protein-rich foods solely based on total gram amounts. Total grams of protein are important. But they do not adequately address the issue of protein quality.

"Protein quality" is a common way of referring to the building blocks that are used to construct a protein. These building blocks are called amino acids. Amino acids are so important that we have given them their own nutrient on our website. But we want to mention enough about amino acids in this protein profile so that we can give you helpful guidelines for obtaining protein from your foods.

There are 20 different amino acids most commonly used to construct proteins. Different types of proteins require different combinations of amino acids because they have different roles to play in the body. Some proteins are quite small and only contain a few dozen total amino acids. Other proteins are extremely large and can contain tens of thousands of total amino acids. Most of the time, however, there are several hundred amino acids per protein, with several dozen of any particular amino acid. As you can see, it is common for proteins to provide significantly different amounts of both total and individual amino acids.

In addition to this significant amino acid diversity in forming proteins themselves so that they can serve the proper functions in our body, proteins also act as a "delivery systems" to provide our body with individual amino acids (or short chains of amino acids called peptides). Because proteins can be broken down in our digestive tract, they can serve as a way to provide our body with patterned amounts of individual amino acids. In other words, sometimes a protein is valuable in and of itself, and at other times it is valuable for the individual amino acids that it contains.

There are ongoing debates about the best way to measure the health benefits associated with the amino acid content of proteins. All of these debates fall under the heading of "protein quality," and you can learn more about this issue in our amino acids profile . However, regardless of the specific approach that is taken to protein quality, we believe that it is helpful to consume proteins that are rich in a variety of different amino acids. For example, we believe that sulfur-containing amino acids have a special value all their own, in the same way as branched-chain amino acids or aromatic amino acids. The best way to obtain a rich variety of amino acids from all of these smaller amino acid subgroups is to regularly enjoy a diversity of foods. More specifically, we would single out the following plant food groups as especially helpful to include over a 3-4 day period in your meal plan in order to obtain a healthy diversity of amino acids: Beans & Legumes, Nuts & Seeds, Vegetables, and Whole Grains. If you consume animal foods, you will find protein-rich choices in all types of animal foods ranging from Poultry & Meats to Seafood to Dairy & Eggs.

One final note in this Basic Description section for protein: while we have adopted the Daily Value (DV) recommendation for protein intake of 50 grams per day, we think about this level as a minimum rather than optimal amount. The reason for our approach involves a growing amount of new research that suggests potential benefits from higher levels of protein intake. While we provide more details about this research in our Role in Health Support section, it's important to know that a diet of 1,800 calories with 15% of those calories coming from protein would contain 67 grams of protein, and if 20% came from protein, that amount would jump up to 90 grams. Dietary studies involving 15-20% protein are becoming more and more common in nutrition research, and we believe the trend shows potential benefits to protein intake in this range.

Role in Health Support

It is impossible to find a general system in the body that does not rely on protein for healthy functioning. As outlined in our Basic Description section, all of our cells require proteins to exist. In addition, metabolic activities throughout our body require enzymes in order to function properly, and all of these enzymes are proteins. Hormones, nervous system messaging molecules (neurotransmitters), digestive enzymes, energy-producing enzymes—all depend on protein. However, it can be difficult to determine the exact levels or qualities of protein that are needed to support these many different body processes. For example, we know that all enzymes are proteins. But we don't know what level or quality of protein intake results in the best enzyme activity. The paragraphs below are designed to highlight some of the more recent findings on dietary protein and health benefits related to this key nutrient.

Maintaining the Integrity of Body Structures

Proper functioning of muscles and healthy formation of connective tissue (the structure that supports and connects our organs) both require sufficient protein intake. In recent studies on aging, adequate protein intake has been associated with decreased

risk of hip fracture. This association is likely to be related to the role of protein in supporting healthy muscles and connective tissue. Interestingly, there is some evidence of better support when protein is consumed at the level of 1.2 grams per kilogram of body weight versus 0.8 grams. Since a 154-pound person would weigh 70 kilograms, this lower amount would translate in 56 grams of protein for a 154-pound person, while the higher amount would translate into 84 grams. Of course, the sturdiness of the body depends on far more than just adequate nourishment, since the strength, flexibility, and resilience of muscles and connective tissue require healthy amounts of physical activity and other lifestyle practices.

Improved Body Composition

Protein intake has been a much-debated subject in relationship to body weight and body composition. As a general rule, no specific amount or quality of protein intake can single-handedly improve a person's body composition or promote a healthier body weight. Body composition and body weight depend too heavily on many other factors, including calorie intake, fat intake, activity level, and hormonal balance - to name just a few. However, recent studies show potentially important roles for protein in helping to regulate appetite and alter various aspects of metabolism in a way that helps balance body composition. (In most studies, body composition was measured using body mass index, waist circumference, skinfold thickness, or similar measurements.) In addition, some studies show improved weight control when protein intake represents approximately 15-20% of total calorie intake rather than 10-15%. As mentioned earlier, an 1,800-calorie diet would provide 45 grams of protein at the 10% level, 67 grams of protein at the 15% level, and 90 grams of protein at the 20% level. In other words, a 15-20% protein diet would typically provide substantially more grams of total protein than the 50-gram Daily Value level.

It's worth noting that in most of the studies that we have reviewed, average protein intake associated with improved body composition has always started out above the DV level of 50 grams. Instead, protein intake has generally fallen into the 65-100 gram range. Interestingly, one group of researchers has suggested a general ballpark level of about 30 grams of protein per major meal as a helpful amount in regulating body weight and body composition. We want to emphasize the speculative nature of this recommendation, and also emphasize the great extent to which body weight and body composition fall under the control of other factors besides diet (for example, physical activity level). Still, we believe that there is a research trend here suggesting possible benefits for body composition with protein intake above the Daily Value.

Improved Blood Sugar Regulation

Adequate protein in meals and snacks has long been a mainstay in dietary advice for improved blood sugar regulation. The benefits of protein-rich foods for blood sugar control are largely due to two factors. First, protein is a nutrient that digests at a moderate pace. Protein is one of three basic "macronutrients." Macronutrients are nutrients that we need in relatively large (gram-sized) amounts. Among the three basic macronutrients, carbohydrates can often digest quite quickly. Fats, by contrast, often digest quite slowly. Protein is typically in the middle, and this intermediate position of protein digestion tends to help stabilize food digestion and blood sugar balance. Second, protein-rich foods tend to have very low glycemic index (GI) values. (While GI is related to speed of digestion, it is a measurement that is also related to other aspects of food digestion.) At WHFoods, the vast majority of our profiled foods (86 out of 100) have a GI value of either very low or low. Only 13 WHFoods have a medium GI score, and only 1 WHFood (potato) has a high GI score. Importantly, all of our Top 10 Protein-Rich foods score "very low" in GI, and all of our Top 25 Protein-Rich foods score either "very low" or "low". By contrast, none of our 14 foods with either "medium" or "high" GI scores rank as good, very good, or excellent protein sources. So as you can see, there is a very natural fit between protein-rich foods and foods that help stabilize blood sugar levels.

While there is no question that protein-rich foods can help to stabilize blood sugar levels, there remain plenty of questions about the total amount of protein intake that is best for blood sugar control. Studies on type 2 diabetes and insulin resistance show some mixed findings with respect to protein intake levels. On the one hand, some studies show improved insulin resistance and blood sugar regulation with protein intake in the 20-30% of total calories range. We've also seen a study showing a slight but perhaps still significant decrease in hemoglobin A1c levels (a lab test used to determine average blood sugar level over a 2-3 month period of time) in persons with type 2 diabetes when consuming protein in the range of 26-32% total calories for 6 months. At the same time, however, several large-scale studies have failed to show similar results. We suspect that this inconsistency in research findings is mostly related to the overall quality of the diets being consumed, and to other factors that extend beyond diet. For example, excessive intake of calories, or excessive intake of processed foods, or intake of high glycemic index foods could easily offset any potential benefits associated with higher levels of protein intake. And in studies where these factors were not fully controlled, we would not expect to see benefits from protein intake above the Daily Value. Similarly, factors unrelated to diet - like amount of exercise - also play a major role in blood sugar and insulin balance.

In summary, it is clear that protein-rich foods can help improve blood sugar and insulin levels. Having protein-rich foods on a meal-by-meal basis seems important in this regard. However, it is not clear whether total protein intake above the DV level is

consistently helpful for improving blood sugar balance, even though some studies show benefits from higher levels of protein intake.

Other Potential Health Benefits

Two other areas of potential health benefit deserve special mention when considering protein intake. One area involves immune support, and the other area involves support of the cardiovascular system.

One of the most famous aspects of our immune system are its antibodies. Antibodies are molecules that help to identify and neutralize potential dangers to the body, for example, certain viruses and bacteria. What might be a lesser known fact about antibodies is that they actually proteins belonging to a special protein category called immunoglobulins. Our immune system relies on protein for production of other molecules as well, including complement proteins that are critical in supporting the function of our white blood cells. Without adequate supplies of protein, our immune system cannot mobilize adequate supplies of antibodies. In fact, one severe condition involving protein deficiency—called kwashiorkor—is well-known for triggering immune system-related problems.

The connection between immune function and protein status has been well-studied in athletes. Changes in blood flow during high-intensity exercise place strong demands on the immune system and redistribution of white blood cells. In the hours following intense exercise, the ability of the immune system to conduct good surveillance of the body is easily compromised, and for this reason, sufficient protein intake to restore healthy immune function can be important. Some studies show that a helpful level of protein intake for training athletes may require at least 20% of total calories. While this percentage may not sound particularly high, it is important to remember that a training athlete may consume 2,500 calories per day or more. At this calorie level, 20% protein would mean about 125 grams or higher.

In some studies on aging, risk of inflammatory disease has been shown to decrease with protein intake of 1.0 - 1.5 grams per kilogram of body weight. For a person weighing 154 pounds, this formula would mean 70 - 105 grams of daily protein. However, we also want to point out that in some other studies on aging, high protein intake has been shown to have the opposite impact: in these studies, low protein, high carbohydrate diets have slowed down the decline in immune system problems when compared with high protein, low carbohydrate diets. We suspect that the conflicting results in this area of protein, immune system and aging are largely due to the fact that total protein grams are not sufficient in and of themselves to provide us with immune system support. Instead, this total amount of protein must be evaluated within the bigger context of protein quality, overall dietary intake, and overall body health (including the health of the lungs, kidneys, and other body systems that can become compromised over the course of aging).

Potential cardiovascular benefits from protein intake greater than the Daily Value have a second research area with mixed findings. In one study, the fat content of liver cells (in the form of triglycerides) was found to be increased by a high carbohydrate (60% of total calories) and low protein (5% of total calories) diet, in comparison to a high protein (30% of calories) and low carbohydrate (35% of calories) diet. Similarly, risk of coronary heart disease associated with an 1,800-calorie diet emphasizing plant protein (93 grams) was found to be somewhat lower than the risk associated with a similar diet containing only 49 grams of plant-based protein. However, other studies have found no difference in risk associated with moderate versus high levels of protein intake, and even when differences have been found, they have not turned out to be statistically significant. Finally, we have reviewed a large-scale study on high blood pressure showing an association between high levels of protein intake (in the vicinity of 100 grams per day) and significantly decreased risk of high blood pressure over an 11-year period of time.

Since no whole food consists of pure protein, these cardiovascular-related studies surely encourage us to place protein intake into a bigger context. If proteins come from low quality foods, or are woven into a poorly balanced overall diet, it seems unlikely for greater amounts to lower our risk of cardiovascular problems (or any other problems). However, within the context of a well-balanced, high-quality, whole foods diet, protein intake above the Daily Value may offer important benefits.

Summary of Food Sources

It's probably not going to come as much of a surprise that fish, poultry and meats are our most abundant sources of protein. In fact, no other WHFoods make it into our Top 10 list when measured exclusively by the sheer amount of protein that they provide in grams. Meats and poultry also make up almost 40% of the protein intake of an average U.S. adult, with another 30% coming from fish, eggs, and dairy foods. Of course, these percentages simply reflect the food preferences of an average U.S. adult, and by no means imply that 70% of your protein intake should come from animal foods. Obtaining optimal protein intake does not require anyone to eat any animal foods.

Among plant foods, legumes tend to be strong sources of protein. We list a number of legumes that contain 30% or more of your daily protein need per one cup serving. Even when enjoyed in the form of a soup (like our Italian Navy Bean Soup with Rosemary), you can get close to 15 grams of protein from the legume-based nature of this recipe and many others. .

Nuts, seeds, and whole grains can all be significant contributors to protein intake. Expect that a serving of any of these three food groups should contain around 10-15% of your daily requirement. One ounce of pumpkin seeds can add 5 grams of protein to your daily meal plan. So can one cup of brown rice.

Vegetables can contain more protein than you might guess. Some categories of vegetable, brassicas and greens, for instance, can contain 5-10% of your protein needs per serving. You'll be getting over 5 grams of protein from a single cup of spinach or collards, and over 7 grams from a single cup of green peas.

Since it is fairly easy to build a diet that meets your protein needs using meats, poultry, and fish,, we'll not discuss this scenario in any detail. It is really as easy as eating one serving of meat, poultry or fish, and then getting enough calories from whole foods to fill out the rest of your day. Four ounces of chicken or turkey will put you at about 35 grams, while 4 ounces of most fish and meats will put you at about 25 grams. With any of these options, you will only be using up about 8-10% of your total daily calories (assuming an 1,800-calorie meal plan) and are almost guaranteed to get your remaining 15-25 grams from the other whole foods that you consume.

Let's instead attempt to build out a diet that meets protein needs using only vegetarian choices. At breakfast, let's start with 10-minute Energizing Oatmeal. This will start our day with 14 grams of protein, or about 30% of our daily requirement. For lunch, we'll choose the Fettuccini with Spinach Pesto, to get another 19 grams of protein. For dinner, let's do Black Bean Chili. Here, we'll get another 24 grams to round out our day.

We're already well over the protein Daily Value of 50 grams,, but since we're only at about 1300 calories, we'll want to add a couple of snacks or treats. About mid-afternoon, if our energy is down, we could include some 10-minute Peanut Bars, a snack that provides about 4 grams of protein. Perhaps we then could cap the day with the 10-Minute Fresh Berry Dessert with Yogurt and Chocolate for another 7 grams of bedtime protein. This sample day provides us with 68 grams of plant-based protein and doesn't go out of its way to focus on high-protein foods.

Introduction to Nutrient Rating System Chart

In order to better help you identify foods that feature a high concentration of nutrients for the calories they contain, we created a Food Rating System. This system allows us to highlight the foods that are especially rich in particular nutrients. The following chart shows the World's Healthiest Foods that are either an excellent, very good, or good source of protein. Next to each food name, you'll find the serving size we used to calculate the food's nutrient composition, the calories contained in the serving, the amount of protein contained in one serving size of the food, the percent Daily Value (DV%) that this amount represents, the nutrient density that we calculated for this food and nutrient, and the rating we established in our rating system. For most of our nutrient ratings, we adopted the government standards for food labeling that are found in the U.S. Food and Drug Administration's "Reference Values for Nutrition Labeling." Read more background information and details of our rating system.

World's Healthiest Foods ranked as quality sources of protein						
Food	Serving Size	Cals	Amount (g)	DRI/DV (%)	Nutrient Density	World's Healthiest Foods Rating
Tuna	4 oz	147.4	33.06	66	8.1	excellent
Cod	4 oz	96.4	21.24	42	7.9	excellent
Chicken	4 oz	187.1	35.18	70	6.8	very good
Turkey	4 oz	166.7	34.17	68	7.4	very good
Soybeans	1 cup	297.6	28.62	57	3.5	very good
Salmon	4 oz	157.6	26.59	53	6.1	very good
Beef	4 oz	175.0	26.16	52	5.4	very good
Shrimp	4 oz	134.9	25.83	52	6.9	very good
Lamb	4 oz	310.4	25.57	51	3.0	very good
Scallops	4 oz	125.9	23.29	47	6.7	very good
Sardines	3.20 oz	188.7	22.33	45	4.3	very good
Tofu	4 oz	164.4	17.89	36	3.9	very good

Spinach	1 cup	41.4	5.35	11	4.7	very good
Asparagus	1 cup	39.6	4.32	9	3.9	very good
Beet Greens	1 cup	38.9	3.70	7	3.4	very good
Mustard Greens	1 cup	36.4	3.58	7	3.5	very good
Swiss Chard	1 cup	35.0	3.29	7	3.4	very good
Bok Choy	1 cup	20.4	2.65	5	4.7	very good
Tempeh	4 oz	222.3	20.63	41	3.3	good
Lentils	1 cup	229.7	17.86	36	2.8	good
Dried Peas	1 cup	231.3	16.35	33	2.5	good
Pinto Beans	1 cup	244.5	15.41	31	2.3	good
Kidney Beans	1 cup	224.8	15.35	31	2.5	good
Black Beans	1 cup	227.0	15.24	30	2.4	good
Navy Beans	1 cup	254.8	14.98	30	2.1	good
Lima Beans	1 cup	216.2	14.66	29	2.4	good
Garbanzo Beans	1 cup	269.0	14.53	29	1.9	good
Pumpkin Seeds	0.25 cup	180.3	9.75	20	1.9	good
Peanuts	0.25 cup	206.9	9.42	19	1.6	good
Yogurt	1 cup	149.4	8.50	17	2.0	good
Green Peas	1 cup	115.7	7.38	15	2.3	good
Cheese	1 oz	114.2	7.06	14	2.2	good
Oats	0.25 cup	151.7	6.59	13	1.6	good
Eggs	1 each	77.5	6.29	13	2.9	good
Collard Greens	1 cup	62.7	5.15	10	3.0	good
Brussels Sprouts	1 cup	56.2	3.98	8	2.6	good
Cow's milk	4 oz	74.4	3.84	8	1.9	good
Broccoli	1 cup	54.6	3.71	7	2.4	good
Kale	1 cup	36.4	2.47	5	2.4	good
Green Beans	1 cup	43.8	2.36	5	1.9	good
Cauliflower	1 cup	28.5	2.28	5	2.9	good
Cabbage	1 cup	43.5	2.27	5	1.9	good
Miso	1 TBS	34.2	2.01	4	2.1	good
Soy Sauce	1 TBS	10.8	1.89	4	6.3	good
Sea Vegetables	1 TBS	10.8	1.81	4	6.0	good
Mushrooms, Crimini	1 cup	15.8	1.80	4	4.1	good
Turnip Greens	1 cup	28.8	1.64	3	2.0	good
Summer Squash	1 cup	36.0	1.64	3	1.6	good
Tomatoes	1 cup	32.4	1.58	3	1.8	good

World's Healthiest Foods Rating	Rule
excellent	DRI/DV>=75% OR Density>=7.6 AND DRI/DV>=10%
very good	DRI/DV>=50% OR Density>=3.4 AND DRI/DV>=5%
good	DRI/DV>=25% OR Density>=1.5 AND DRI/DV>=2.5%

Impact of Cooking, Storage and Processing

Our steaming, boiling, and healthy sauté cooking methods will not result in any significant protein loss from any of our WHFoods. Nor will storage of these foods using our recommended approach and suggested time frames. Protein tends to be a stable nutrient within the above context.

Proteins and their amino acids can interact with sugars under certain circumstances to form other compounds. Many of these chemical reactions - for example, the Maillard reaction - are actually very complicated in terms of their biochemistry and have yet to be fully researched. One possible result of protein-sugar interactions involves formation of molecules called advanced glycation end-products, or AGES. When excessive numbers of AGEs are formed in the body, we know that they can contribute to increased risk of chronic diseases including atherosclerosis, osteoarthritis, cataracts, neurodegenerative diseases, and cataracts. Relatively recent research indicates that AGEs can not only get preformed in food but can get absorbed up into our body in significant amounts and contribute to the "pool" of AGEs that have already been formed as a result of our own metabolism. The cooking methods that appear mostly likely to increase AGE formation in protein-rich foods including grilling, searing, and frying. Formation of AGEs from protein-sugar interactions is one of the reasons we avoid these cooking methods at WHFoods. A second area of concern in protein cooking involves possible formation of acrylamides. Potato chips, french fries, and grain-based coffee substitutes are processed foods in which acrylamide formation has been most extensively studied. You can find many more details in our Q & A, What is acrylamide and how is it involved with food and health?

Finally, we would like to note that caramelization of food (as exemplified by the heating and browing of onions) is not a protein-based chemical reaction but a reaction only involving food sugars and is not the same as the above-described AGE formation and acrylamide formation processes.

Risk of Dietary Deficiency

If you eat animal foods—meat, fish, dairy, eggs—on a daily basis, you are very likely to be meeting or exceeding the Daily Value of 50 grams for protein.

However, you don't need to eat animal foods much or even at all to meet the DV. . An average American lacto-ovo-vegetarian (a vegetarian who eats dairy and eggs) eats 89 grams of protein per day, almost twice the Daily Value (DV) of 50 grams. Even when we subtract the contributions of dairy and eggs, we still see about 60 grams of protein from purely plant sources.

It would actually be quite difficult to design a whole foods diet that provided less than 10% of its calories from protein. An 1,800-calorie whole foods diet consisting exclusively of fruit, for example, would typically still provide at least 40 grams of protein. An 1,800 calorie whole foods diet consisting exclusively of broccoli would provide 121 grams! Of course, we would never recommend either of these approaches to a meal plan, but they are helpful in demonstrating just how difficult it is to come up with a highly protein deficiency diet based on a whole foods approach to eating.

More up in the air is the question of health benefits from a meal plan that greatly exceeds the protein DV of 50 grams. As discussed earlier, we have seen the develop of a research trend that suggests possible advantages to a meal plan in which protein represents 15-25% of total calories (67-112 grams) instead of the 11% level represented by 50 grams. We definitely look forward to more research in this area.

Other Circumstances that Might Contribute to Deficiency

Disordered eating patterns can lead to protein-energy malnutrition, which can often become quite serious. As many as 24 million Americans suffer from one or more eating disorders. These disorders are often undiagnosed, and only one in ten people receives the medical treatment these conditions often require.

There are some severe disease states that cause an increase in protein breakdown. In these conditions, it may be difficult or even impossible to eat enough dietary protein to offset the loss.

While many sources recommend it, the National Academy of Sciences does not recommend a different protein requirement based on level of physical activity. The American College of Sports Medicine, however, does recommend at least paying attention to protein intake to make sure that needs are met during times of intensive training. You will find this issue discussed in more detail in our earlier section entitled "Other Potential Health Benefits" in our Role in Health Support section.

Relationship with Other Nutrients

As your protein intake goes up, so can your urinary loss of calcium. This phenomenon is related to the use of calcium as a buffer when proteins or their amino acids are primarily acidic. However, from a research standpoint, the jury is out on exactly how this natural physiologic process relates to any potential health risks. (For example, too much extraction of calcium from our bones could increase our risk of osteoporosis.) We expect future studies to help clarify the nature of these protein-and-calcium relationships. As mentioned earlier in our Impact of Cooking, Storage, and Processing section, proteins and amino

acids can react with certain types of sugars to produce advanced glycosylation end-products (AGEs) and other compounds (including acrylamides). Please see that earlier section for more detail.

Risk of dietary Toxicity

The National Academy of Sciences (NAS) established an Acceptable Macronutrient Distribution Ranges (AMDRs) for protein in 2005. Important, the NAS did not consider these ranges to be Dietary Reference Intake guidelines that established specific upper (or lower) limits for protein intake. Instead, these AMDRs were viewed as general guidelines that could be considered helpful in potentially lowering disease risk. These 2005 AMDRs for protein were established as follows:

- Adults: 10-35% of total calories
- Children 1-3 years: 5-20% of total calories
- Children and Teens 4-18 years: 10-30% of total calories

Let's take the adult guidelines of 10-35% and translate these percentages into more practical terms. And let's start out with the high end guideline for protein intake of 35% total calories. Here are the grams of protein that correspond to 35% of total calories at different calorie levels:

- 131 grams of protein in a 1,500-calorie diet
- 157 grams of protein in an 1,800-calorie diet
- 175 grams of protein in a 2,000-calorie diet
- 219 grams of protein in a 2,500-calorie diet

Now let's look at the low end of this protein guideline (10% of total calories). Here are the grams of protein that correspond to 10% of total calories at different calorie levels:

- 38 grams of protein in a 1,500-calorie diet
- 45 grams of protein in an 1,800-calorie diet
- 50 grams of protein in a 2,000-calorie diet
- 63 grams of protein in a 2,500-calorie diet

Since the Daily Value (DV) for protein is based on a 2,000-calorie meal plan, you can see how this lower limit of the AMDR for protein hits exactly at that 10% level. However, in this section on Risk of Dietary Toxicity, it is the high end of the AMDR that we are most concerned about, and you can see how this high end very roughly corresponds to protein intake in the 150-200 gram per day range.

It is very hard in practice to go beyond this level from whole foods! Whole foods set a natural limit on the total amount of protein that you can consume within any fixed amount of calories, because no whole food consists of pure protein. Instead, protein-containing whole foods also contain varying amounts of fat, and fat is a nutrient that contains more than double the calories of protein. So as a result, all whole foods end up increasing their calories at a quicker rate than their grams of protein. These ratios between protein, fat, and calories in whole foods enable you to stay within the AMDR guidelines in virtually any balanced meal plan.

Disease Checklist

- Anorexia and other eating disorders
- Malabsorption disorders
- Heavy exercise
- Weight loss
- Diabetes prevention
- Immunodeficiency problems
- Problems with insulin resistance

Public Health Recommendations

In 2005, the National Academy of Sciences established a set of Dietary Reference Intakes (DRIs) for protein that included age and gender specific Recommended Dietary Allowances (RDAs) for protein. Note that the recommendations for infants from 0-6 months of age were established as Adequate Intake (AI) levels. The complete set of DRIs is as follows: .

- 0-6 months: 9.1 grams
- 6-12 months: 11 grams
- 1-3 years: 13 grams
- 4-8 years: 19 grams
- 9-13 years: 34 grams
- 14-18 years, female: 46 grams
- 14-18 years, male: 52 grams
- 19+ years, female: 46 grams
- 19+ grams, male: 56 grams
- Pregnant women: 71 grams
- Lactating women: 71 grams

Note that for adults, these RDA assume an average body weight of 70 kg (or 154 lbs) for a male and 57.5 kg (or 126 lbs) for a female. For people significantly different from these target weights, you may choose to include 0.8 grams of dietary protein per kilogram (about 2.2 pounds) of body weight.

In 2005 the National Academy of Sciences (NAS) also issued a set of Acceptable Macronutrient Distribution Ranges (AMDRs) for protein as a percentage of total calories. They recommend keeping protein calories between 5 and 20% of calorie total in ages 1-3 years, 10 to 30% in children ages 4-18, and 10-35% in adults. The NAS did not consider these AMDRs to be part of the Dietary Reference Intakes (DRIs), but rather very general guidelines with the potential to lower risk of health problems. In our Risk of Dietary Deficiency section, you can find practical details about these AMDR guidelines.

The Daily Value (DV) recommendation for protein is 50 grams per day for adults. This is the standard you will see listed on food labels. It is also the standard that we have adopted at WHFoods as our recommended minimal amount of daily protein intake.

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The World's Healthiest Foods

World's Healthiest Foods rich in selenium		
Food	Cals	DRI/DV
Tuna	147	223%
Shrimp	135	102%
Sardines	189	87%
Salmon	158	78%
Turkey	167	62%
Cod	96	58%
Chicken	187	57%
Lamb	310	51%
Scallops	126	45%
Beef	175	44%

Basic Description

Selenium is one of many important dietary minerals, and we require a small amount of selenium in our daily diet. Selenium is incorporated in a small cluster of important proteins, each of which plays a critical role in our health. Scientists named these selenium-containing proteins "selenoproteins."

Selenium has received publicity over the past couple decades based on some confusing and contradictory research about whether low-selenium diets are implicated in cancer risk. To date, this is still a question without a clear answer. Regardless of whether selenium deficiency is associated with increased risk of cancer, it is clear that good selenium nutrition is important for antioxidant protection and for other health reasons as well.

The selenium content of plant foods is often closely related to selenium content of soil in which the plants have been grown. Selenium content of soils can vary widely, including in the U.S. However, poor soil content of selenium is not typically a factor in the average U.S. diet, and the U.S. population 2 years and older averages over 100 micrograms of selenium per day. (This amount easily exceeds all common public health recommendations.)

Most of our food groups at WHFoods provide valuable amounts of selenium. Fish, grass-fed and pasture-raised meats, whole grains, and nuts and seeds are either good, very good, or excellent food sources of selenium.

We rate nine of the World's Healthiest Foods as excellent sources of selenium. We also have eight very good sources and ten good sources of this important mineral.

Role in Health Support

Antioxidant Protection

Selenium is required for the proper activity of a group of enzymes called glutathione peroxidases. (You'll sometimes see the abbreviation "GPO" or "GPx" for a glutathione peroxidase enzyme.) These enzymes play a key role in the body's detoxification system and they also provide protection against oxidative stress. (Oxidative stress is physiological circumstance in which there is excessive risk of oxygen-related damage to the body.) Of the eight known glutathione peroxidase enzymes, five of them require selenium.

In addition to the activity of glutathione peroxidase, selenium-containing enzymes are involved in recycling of vitamin C from its spent form back to its active one, allowing for greater antioxidant protection.

Support Normal Thyroid Function

A selenium-containing enzyme is responsible for transforming a less active thyroid hormone called T4 into the more active T3. As you'll see below in the Relationship with Other Nutrients section, selenium and iodine work together to keep thyroid function strong and consistent.

Like the antioxidant protection issue, this is not just an esoteric concern. Researchers have been able to induce problems with the thyroid gland in just two months of a low-selenium diet.

Summary of Food Sources

Probably, if you've read about food sources of selenium, you've read about Brazil nuts as a strong source of the mineral. Depending on where they are grown, this is likely to be true—one ounce of Brazil nuts may contain as much as 10 times the Dietary Reference Intake (DRI) recommendation for selenium intake. Other exceptionally selenium-rich foods include oysters, clams, liver, and kidney. Each of these foods is likely to contain double to triple the DRI in a serving. These foods are the exception, however, and not the rule.

As a more general rule of thumb, we can identify the best sources of selenium by food group. Fish and shellfish make up an outsized proportion of our excellent and very good sources. After these come other animal meats, many of which fall in the very good category. Close behind are whole grains and seeds, both of which are well-represented in our good selenium sources category.

Almost all the World's Healthiest Foods contain at least some selenium. Because of this widespread availability, we believe that selenium is a mineral you'll have little trouble getting from our recipes.

Introduction to Nutrient Rating System Chart

In order to better help you identify foods that feature a high concentration of nutrients for the calories they contain, we created a Food Rating System. This system allows us to highlight the foods that are especially rich in particular nutrients. The following chart shows the World's Healthiest Foods that are either an excellent, very good, or good source of selenium. Next to each food name, you'll find the serving size we used to calculate the food's nutrient composition, the calories contained in the serving, the amount of selenium contained in one serving size of the food, the percent Daily Value (DV%) that this amount represents, the nutrient density that we calculated for this food and nutrient, and the rating we established in our rating system. For most of our nutrient ratings, we adopted the government standards for food labeling that are found in the U.S. Food and Drug Administration's "Reference Values for Nutrition Labeling." Read more background information and details of our rating system.

World's Healthiest Foods ranked as quality sources of selenium						
Food	Serving Size	Cals	Amount (mcg)	DRI/DV (%)	Nutrient Density	World's Healthiest Foods Rating
Tuna	4 oz	147.4	122.70	223	27.2	excellent
Shrimp	4 oz	134.9	56.13	102	13.6	excellent
Sardines	3.20 oz	188.7	47.81	87	8.3	excellent
Salmon	4 oz	157.6	43.09	78	8.9	excellent
Cod	4 oz	96.4	31.75	58	10.8	excellent
Mushrooms, Crimini	1 cup	15.8	18.72	34	38.7	excellent
Mushrooms, Shiitake	0.50 cup	40.6	17.98	33	14.5	excellent
Asparagus	1 cup	39.6	10.98	20	9.1	excellent
Mustard Seeds	2 tsp	20.3	8.32	15	13.4	excellent
Turkey	4 oz	166.7	34.25	62	6.7	very good
Chicken	4 oz	187.1	31.30	57	5.5	very good
Lamb	4 oz	310.4	27.90	51	2.9	very good
Scallops	4 oz	125.9	24.61	45	6.4	very good
Beef	4 oz	175.0	23.93	44	4.5	very good
Barley	0.33 cup	217.1	23.12	42	3.5	very good
Tofu	4 oz	164.4	19.73	36	3.9	very good
Eggs	1 each	77.5	15.40	28	6.5	very good
Brown Rice	1 cup	216.4	19.11	35	2.9	good
Sunflower Seeds	0.25 cup	204.4	18.55	34	3.0	good
Sesame Seeds	0.25 cup	206.3	12.38	23	2.0	good
Cow's milk	4 oz	74.4	4.51	8	2.0	good

Flaxseeds	2 TBS	74.8	3.56	6	1.6	good
Cabbage	1 cup	43.5	3.45	6	2.6	good
Spinach	1 cup	41.4	2.70	5	2.1	good
Garlic	6 cloves	26.8	2.56	5	3.1	good
Broccoli	1 cup	54.6	2.50	5	1.5	good
Swiss Chard	1 cup	35.0	1.57	3	1.5	good

World's Healthiest Foods Rating	Rule
excellent	DRI/DV>=75% OR Density>=7.6 AND DRI/DV>=10%
very good	DRI/DV>=50% OR Density>=3.4 AND DRI/DV>=5%
good	DRI/DV>=25% OR Density>=1.5 AND DRI/DV>=2.5%

Impact of Cooking, Storage and Processing

Like other minerals, selenium content of foods tends to be stable during storage. Consult each specific World's Healthiest Food profile for tips on how to best select and store for optimal nutrient content.

Animal foods tend to lose little selenium in cooking or processing. For example, the amount of selenium lost in the canning process of common seafood was marginal—less than 10% of the total pre-cooking amount. Similarly, broiling beef does not lead to significant loss of the rich selenium content.

Processing whole grains is much more detrimental to selenium content. Making 60% extraction wheat flour from 100% whole wheat robs it of just shy of half of the selenium content. (It is 60% extraction wheat flour that is the most common type used in production of breads in the U.S. where the bran and the germ of the grain have been removed and the flour has become lighter in color.)

Risk of Dietary Deficiency

According to the third National Health and Nutrition Study (NHANES III), the risk of selenium deficiency is very low. The average U.S. adult eats about 106 mcg of dietary selenium per day. This is well above the Dietary Reference Intake (DRI) recommendation of 55 mcg.

Looking deeper into national eating patterns, we do not see any age or gender group at significant risk of selenium deficiency. Even small children in the United States average above the adult DRI intake recommendation.

Other Circumstances that Might Contribute to Deficiency

We are not aware of common risk factors for deficiency of selenium in the United States. As mentioned earlier, the average U.S. diet exceeds all common public health recommendations for intake of this mineral. For this reason, is it not common to find research studies showing other reasons for selenium deficiency in the U.S.

When we have come across selenium deficiency studies related to the U.S. population, non-dietary factors tend to be medical. For example, we have seen bowel surgeries—especially weight loss surgeries—associated with symptomatic deficiency of selenium. Also, malabsorption problems can lead to selenium deficiency. These need to be severe, however, and again are uncommon and would be associated with deficiency of many nutrients in addition to selenium.

Relationship with Other Nutrients

In otherwise well-nourished individuals, selenium deficiency is a relatively silent condition. In fact, maybe uniquely among nutrients, a deficiency of other vitamins or minerals is probably required for overt symptoms to emerge.

If a person is also deficient in other key antioxidants, particularly vitamin C and vitamin E , the problems related to disruptions in antioxidant protection can be amplified. Many of our recipes—such as Steamed Salmon and Asparagus —combine strong

sources of multiple antioxidant nutrients. .

A deficiency of both selenium and iodine can make thyroid disorders more severe than a deficiency of iodine alone. Thankfully, the level of selenium deficiency needed to create this combined effect is severe, and not common in the U.S. . This Huevos Rancheros recipe is a good source of both selenium and iodine.

Risk of dietary Toxicity

The National Academy of Sciences has set the Tolerable Upper Intake Level (UL) of selenium intake at 400 mcg per day. Based on data from the National Health and Nutrition Study, it doesn't appear that we eat more than this amount very frequently.

In practical terms, most of our excellent and very good sources of selenium contain from 25 to 60 mcg. To routinely go above the UL for selenium intake, you would need to have about 5 or more servings of these high-selenium foods on top of a number of more moderate selenium sources every day.

Reflecting this set of relationships, our Healthiest Way of Eating Plan averages about one fourth of this UL level. From our perspective, this amount gives you plenty of room for remaining well below the UL level while still meeting the recommended daily amount.

Disease Checklist

- Immune function
- Depression
- Cardiovascular disease
- Cancer prevention (only if deficient)
- Hypothyroidism
- Infertility (male)

Public Health Recommendations

In the year 2000, the National Academy of Sciences established Dietary Reference Intakes (DRI) for selenium that included Recommended Daily Allowance (RDA) recommendations by age. These DRI recommendations are used as the reference standard for the charts on this page. (The only exceptions here are the recommendations for infants 12 months and under. Those recommendation levels are not RDAs but rather Adequate Intake, or AI levels.)

- 0-6 months: 15 mcg
- 6-12 months: 20 mcg
- 1-3 years: 20 mcg
- 4-8 years: 30 mcg
- 9-13 years: 40 mcg
- 14+ years: 55 mcg
- Pregnant women: 60 mcg
- Lactating women: 70 mcg

The DRI report also established a Tolerable Upper Intake Level (UL) for selenium intake of 400 mcg. This UL is for all selenium intake from foods and supplements and it is established as an amount not be exceeded on any routine basis.

The Daily Value (DV) for selenium intake is 70 mcg per day. This is the standard you'll see on food labels.

As our WHFoods standard, we adopted the DRI value for males and non-pregnant females ages 14 and older of 55 micrograms.

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The World's Healthiest Foods

Important note: we want to make it clear that we added up all forms of vitamin A (including carotenoids like beta-carotene) when we created the list of vitamin A-rich foods below.

World's Healthiest Foods rich in vitamin A		
Food	**Cals**	**DRI/DV**
Sweet Potato	180	214%
Carrots	50	113%
Spinach	41	105%
Kale	36	98%
Mustard Greens	36	96%
Collard Greens	63	80%
Turnip Greens	29	61%
Beet Greens	39	61%
Swiss Chard	35	60%
Winter Squash	76	59%

Basic Description

The term "vitamin A" makes it sound like there is one particular nutrient called "vitamin A," but that is not true. Vitamin A is a broad group of related nutrients. Each of these nutrients provides us with health benefits, but these benefits may be quite different and they may be provided in different ways. Here is a summary chart showing basic relationships between the forms of vitamin A.

Vitamin A-Related Nutrients

Retinoids (found in animal foods)	**Carotenoids (found in plant foods)**	
retinol	**Carotenes**	**Xanthophylls**
retinal	alpha-carotene*	astaxanthin
retinoic acid	beta-carotene*	beta-cryptoxanthin*
retinyl esters	gamma-carotene*	canthaxanthin
	delta-carotene	fucoxanthin
	epsilon-carotene	lutein
	zeta-carotene	neoxanthin
		violaxanthin
		zeaxanthin

*Once a food has been consumed, these carotenoid forms of vitamin A may be converted by the body into retinoid forms under certain conditions.

Retinoids

As you can see in the chart above, there are two basic forms of vitamin A: retinoids (found in animal foods) and carotenoids (found in plant foods). These two forms aren't just chemically different - they also provide us with different types of health benefits. There are some specific immune, inflammatory, genetic, and reproductive-related benefits of vitamin A that can only be obtained from the retinoid forms of the vitamin. These retinoid forms can be especially important with respect to pregnancy and childbirth, infancy, childhood growth, night vision, red blood cell production, and resistance to infectious disease. Yet even if we are not faced with any of these special conditions, each of us needs retinoid forms of vitamin A.

Carotenoids

Like the retinoid forms of vitamin A, the carotenoid forms also provide us with unique health benefits. Most carotenoid forms of vitamin A function as antioxidant and anti-inflammatory nutrients. Sometimes specific carotenoids have a special role to play in the protection of our health. For example, the only carotenoids found inside the retina of the human eye are the xanthophylls lutein and zeaxanthin. Anyone needing to focus on vitamin A benefits related to eye health (for example, prevention of age-related macular degeneration) would need to develop a meal plan that not only included foods that were rich in vitamin A, but more specifically, rich in these two specific carotenoid forms of the vitamin. (Spinach, kale, and Swiss chard would be examples of foods that are rich in lutein and zeaxanthin.)

At first glance, it looks like we need to eat both animal and plant foods in order to get both retinoid and carotenoid forms of vitamin A. In some instances, that is true. However, in some other instances, it is not. In the bodies of many individuals, carotenoid forms of vitamin A can be effectively converted into retinoid forms, therefore providing the physiological functionality noted above. Alpha-carotene, beta-carotene, and beta-cryptoxanthin are three carotenoid forms of vitamin A that can be converted by our body into retinoid forms under certain conditions.

Conversion of Carotenoids to Retinoids

We use this phrase—"under certain conditions"—to refer to the fact that the bodies of many individuals may not be well equipped to convert carotenoid forms of vitamin A into retinoid forms. Many different factors can contribute to problems with this conversion, including: a person's inherited genetic tendencies, digestive problems, bacterial imbalances in the digestive tract, excessive use of alcohol, excessive exposure to toxic chemicals, imbalanced intake of vitamin A and vitamin D as a result of high-dose supplementation, and the use of certain over-the-counter and/or prescription medications. So there is a need for caution here. If you are a person who avoids animal foods and you are trying to obtain more retinoid forms of vitamin A by consuming plant foods that are high in carotenoids, you might get a very large amount of carotenoids yet still be unable to convert these carotenoid forms of vitamin A into the retinoid form that is also required by the body for proper physiological functioning.

If you recognize some of the problem factors in the list above as potentially affecting your own body's ability to convert carotenoid forms of vitamin A into retinoid forms, we recommend that you consult with a healthcare provider to determine possible helpful steps. A healthcare provider with experience in this area may be able to help you improve your digestion, reduce the impact of medications, lessen your toxic exposure, and balance the amounts of vitamins A and D in any supplements that you are taking. Also, while still expensive in the healthcare marketplace, some forms of lab testing—including genetic testing—may be available to help you determine potential vitamin A-related problems.

Two additional important points: (1) if a person's body is effectively able to convert carotenoids into retinoids, beta-carotene is the best carotenoid for the body to work with, since in comparison to alpha-carotene or beta-cryptoxanthin, it takes only half as much beta-carotene for the body to create the same amount of retinol; and (2) if a person's body is effectively able to convert carotenoids into retinoids, there may be some advantages to letting it do so (rather than trying to directly obtain high levels of retinol from food). Allowing the body to decide about the degree of conversion may provide more optimal regulation of both carotenoid and retinoid levels.

Researchers have developed a system for evaluating the degree to which carotenoid forms of vitamin A can be converted into retinoid forms. This system is based on units of measurement called retinol activity equivalents (RAE) and retinol equivalents (RE). RAE and RE are yardsticks for measuring the retinoid-converting potential of carotenoid-containing foods. The higher the RAE or RE, the greater the potential for conversion of carotenoids into retinoids.

We created the chart below to help explain how all of these factors are interrelated.

Top 25 Vitamin A-Containing WHFoods Retinol and Carotenoid Content*

	Food	Total for All Forms (mcg RAE)	Retinol (mcg RE)	Total Carotenoids (mcg RE)	Beta-carotene (mcg)	Lutein & Zeaxanthin (mcg)	Lycopene (mcg)
1	Sweet potato	1922	0	3844	23018	0	0
2	Carrots	1019	0	2038	10108	312	1
3	Spinach	943	0	1887	11318	20354	0
4	Kale	885	0	1771	10625	23720	0

5	Mustard greens	865	0	1732	10360	8347	0
6	Collard greens	722	0	1444	8575	11774	0
7	Turnip greens	549	0	1098	6588	12154	0
8	Swiss chard	536	0	1072	6391	19276	0
9	Winter squash	535	0	1071	5726	2901	0
10	Romaine lettuce	409	0	819	4912	2173	0
11	Bok choy	361	0	722	4333	65	0
12	Cantaloupe	271	0	541	3232	42	0
13	Bell peppers	144	0	288	1494	47	0
14	Parsley	128	0	256	1536	1691	0
15	Broccoli	121	0	241	1449	1685	0
16	Asparagus	91	0	181	1087	1388	54
17	Sea vegetables	81	- -	- -	973	- -	- -
18	Chili peppers	80	0	160	810	17	1
19	Tomatoes	75	0	150	808	221	4631
20	Basil	56	0	112	666	1198	0
21	Papaya	131	0	262	756	246	5045
22	Shrimp	102	102	102	0	0	0
23	Eggs	75	74	75	5.5	176	0
24	Brussels sprouts	61	0	121	725	2012	0
25	Grapefruit (pink/red)	59	0	119	706	8	1453
	Food	**Total for All Forms (mcg RAE)**	**Retinol (mcg RE)**	**Total Carotenoids (mcg RE)**	**Beta-carotene (mcg)**	**Lutein & Zeaxanthin**	**Lycopene (mcg)**

* All values are listed per serving size as identified on our website. Due to unavailability of data, content of many other specific carotenoids (for example, alpha-carotene) is not presented. mcg RAE is microgram retinol activity equivalents. mcg RE is microgram retinol equivalents. mcg is micrograms.

To better understand this chart, it's helpful to start with the third column from the left that is labeled "Total for all forms (mcg RAE)." In this column, you will notice that the numbers drop lower and lower as you move from the first food (Sweet potatoes) and proceed down the list. This column tells you that if you are seeking foods that will provide you with the greatest potential amount of vitamin A in its retinoid form, you are likely to get the best results by choosing Food 1 (Sweet potatoes) versus Food 2 (Carrots), Food 2 (Carrots) versus Food 3 (Spinach), and so on down the list.

Now take a look over at the fourth column in the chart, which is labeled, "Retinol mcg RE." This column tells you that none of the Top 25 Vitamin A-containing foods on our website contain vitamin A in its retinoid form! So how can these foods provide you with the greatest potential for vitamin A in its retinoid form when they don't actually contain any retinoids? The answer lies in their unusually high carotenoid content. Provided that your body has the ability to effectively convert carotenoids into retinoids, you'll actually end up with more retinoid forms of vitamin A by eating any of these Top 25 Vitamin A foods, even though all of these are plant foods that do not directly provide any Vitamin A in retinoid form.

We created a second chart below to show you how the animal-derived foods featured on the website ranked as sources of Vitamin A.

Vitamin A Ranking for WH Animal Foods

	Food	Total for All Forms (mcg RAE)	Retinol (mcg RE)	Total Carotenoids (mcg RE)	Beta-carotene (mcg)	Lutein & Zeaxanthin (mcg)	Lycopene (mcg)
22	Shrimp	102	102	0	0	0	0
23	Eggs	75	74	1	5.5	176	0
26	Cow's milk	56	55	2	8	0	0
33	Cheese	77	73	4	12	0	0
34	Yogurt	67	66	2	12	0	0
35	Salmon	58	58	0	0	0	0
37	Sardines	29	29	0	0	0	0
50	Chicken	7	7	0	0	0	0
61	Turkey	3	3	0	0	0	0
39	Tuna	25	25	0	0	0	0
66	Cod	2	2	0	0	0	0
67	Scallops	2	2	0	0	0	0
not in Top 100	Beef	0	0	0	0	0	0
Not in Top 100	Lamb	0	0	0	0	0	0
	Food	**Total for All Forms (mcg RAE)**	**Retinol (mcg RE)**	**Total Carotenoids (mcg RE)**	**Beta-carotene (mcg)**	**Lutein & Zeaxanthin**	**Lycopene (mcg)**

* All values are listed per serving size as identified on our website. Due to unavailability of data, content of many other specific carotenoids (for example, alpha-carotene) is not presented. mcg RAE is microgram retinol activity equivalents. mcg RE is microgram retinol equivalents. mcg is micrograms.

In this second chart, you'll notice that even though most of our animal foods contain vitamin A in its retinoid form (as shown by those numbers in the fourth column which is labeled, "Retinol (mcg RE)," their carotenoid content is very low (or absent), giving our body very little to work with if it wanted to convert carotenoids into retinoids. The only exception here would be eggs and their relatively high content of the carotenoids lutein and zeaxanthin. Since neither lutein nor zeaxanthin can be converted by the body into retinoids, however, the presence of these carotenoids does not help eggs move up on our ranking list (although they still do not do too badly at number 37 out of more than 125 foods).

We'd like to end this description with four key take-away points:

- There are two basic forms of vitamin A (retinoids and carotenoids) and both forms provide unique health benefits.
- If your body is able to effectively convert carotenoids into retinoids, you don't have to eat animal foods in order to obtain retinoid forms of vitamin A that are essential for health. If your body is unable to do this conversion effectively, you'll either need to include animal foods in your meal plan or obtain retinoid forms of vitamin A through dietary supplements.
- Many factors can compromise the body's ability to convert carotenoids into retinoids, including: genetic tendencies, digestive problems, bacterial imbalances in the gut, excessive alcohol use, excessive exposure to toxins, imbalanced intake of vitamin A and vitamin D in supplement form, and use of over-the-counter and/or prescription medications.
- Some Vitamin A health benefits will require you to eat foods that are rich in specific carotenoids. A great example is eye health and the unique role of two specific carotenoids (lutein and zeaxanthin) in the health of our eyes.

Role in Health Support

How does vitamin A support health?

Retinoid Forms

While vitamin A is best known for its vital role in vision, the retinoid forms of this vitamin also participate in physiological activities related to the immune system, inflammatory system, maintenance of epithelial and mucosal tissues, growth, reproduction, bone development, creation of red blood cells, and production of spermatozoa (male reproductive cells). In food, retinoid forms of vitamin A typically appear as retinyl esters. The body is typically able to convert these retinyl esters into metabolically active forms of vitamin A including retinol, retinal, and retinoic acid.

Vision Support

The human retina contains four kinds of photopigments that store vitamin A compounds. One of these pigments, called rhodopsin, is located in the rod cells of the retina. Rhodopsin allows the rod cells to detect small amounts of light, and, thus, plays a fundamental role in the adaptation of the eye to low-light conditions and night vision.

Retinal, the aldehyde form of the vitamin, participates in the synthesis of rhodopsin, and in the series of chemical reactions that causes visual excitation, which is triggered by light striking the rod cells. The remaining three pigments, collectively known as iodopsins, are found in the cone cells of the retina and are responsible for day vision.

Support of the Immune and Inflammatory Systems

Throughout the body, but particularly in our digestive tract, vitamin A plays a key role in support of immune and inflammatory functions. Our digestive tract can get exposed on a daily basis to potentially unwanted substances (like pesticide residues in food), as well as unwanted micro-organisms (like certain kinds of bacteria). Our immune and inflammatory systems are designed to help prevent us from being harmed by these events.

For example, in order to help neutralize unwanted bacteria and other micro-organisms, our immune system has the ability to make and release antibodies that can block their activity. Our immune and inflammatory systems also have "braking" function that prevents them overreacting. Recent research has shown that vitamin A plays a key role in both of these protective processes. Scientists now know that the T cell and B cells of the immune system cannot be correctly synthesized without vitamin A, nor can immune responses be effectively activated without participation of vitamin A. Interestingly, whenever we undergo an increase in whole body inflammation, our cells also increase their conversion of vitamin A in its retinol form into a second form called retinoic acid. This conversion required participation of two enzymes (alcohol dehydrogenase and retinaldehyde dehydrogenase). The inability of our cells to make this vitamin A conversion is now believed to be a risk factor for increased susceptibility to infection, as well as for poor response to vaccination.

Researchers believe that vitamin A may be equally important for our immune and inflammatory "braking" system, in which our cells are prevented from becoming overreactive. Since some aspects of food allergy can be related to our immune system's overreaction to food proteins, optimal intake of vitamin A may turn out to be important for lowering risk of certain types of food allergy.

Cell Growth Support

Vitamin A is required for normal cell growth and development. Although the mechanisms by which vitamin A promotes cell growth and development are not yet fully understood, it is known that retinoic acid is necessary for the synthesis of many glycoproteins, which control cellular adhesion (the ability of cells to attach to one another), cell growth, and cell differentiation. For example, the production of red blood cells in our bone marrow (through a process called hematopoiesis) is a process that is known to require vitamin A in the form of retinoid acid. As described in the previous paragraph, retinoic acid can be synthesized in our cells from the retinyl esters found in food, and it takes two enzymes (alcohol dehydrogenase and retinaldehyde dehydrogenase) in order for this synthesis to occur. Researchers are actively investigating the link between this enzyme system and cell growth and believe that problems with synthesis of retinoic acid may hold the key for understanding a wide range of problems related to human growth and development.

Other Roles for Vitamin A

It is also known that vitamin A is essential for reproductive processes in both males and females and plays a role in normal bone metabolism. In addition, some of the most cutting-edge research in the field of genetics has been examining the role of vitamin A (in the form of retinoic acid) in regulating genetic events. Vitamin A is also known to be required for proper production of sperm (through a process called spermatogenesis).

Carotenoid Forms

Preventing Vitamin A Deficiency

Until late in the 20th century, the functions of carotenoids were discussed only in terms of their potential to act in the same way as retinoids. From among the more than 600 carotenoids known to exist in plant foods, only three carotenoids - beta-carotene, alpha-carotene, and beta-cryptoxanthin - were designated as "provitamin A" carotenoids that could be converted by the body (under the right circumstances) into retinoids. Intake of these three carotenoids is still regarded as extremely important in preventing deficiency of vitamin A in its retinoid forms.

Antioxidant, Anti-Inflammatory, and Immune-Enhancing Activity

In recent years, carotenoids have received a large amount of research attention as potential anti-cancer and anti-aging compounds. These potential functions of carotenoids are closely related to their antioxidant and anti-inflammatory activity. Importantly, virtually all carotenoids provide antioxidant and anti-inflammatory benefits (even though it's only a handful of carotenoids that can be converted into retinoids).

Promoting Proper Cell Communication

In addition to their antioxidant and immune-enhancing activity, carotenoids have shown the ability to stimulate cell-to-cell communication. Researchers now believe that poor communication between cells may be one of the causes of the overgrowth of cells, a condition that eventually leads to cancer. By promoting proper communication between cells, carotenoids may play a direct role in cancer prevention.

It is also believed that carotenoids participate in female reproduction. Although the exact function of carotenoids in female reproduction has not yet been identified, it is known that the corpus luteum contains a very high level of beta-carotene, suggesting that this nutrient plays an important role in reproductive processes.

Summary of Food Sources

What foods provide vitamin A?

Retinoids forms of vitamin A are provided by animal foods, including the following WHFoods: cow's milk, shrimp, eggs, salmon, halibut, cheese, yogurt, scallops, sardines, tuna, cod, and chicken.

Carotenoid forms of vitamin A are provided by most of the fruits and vegetables on our WHFoods list. Please see the Basic Description section above for a list of the Top 25 plant foods rich in carotenoids.

Introduction to Nutrient Rating System Chart

In order to better help you identify foods that feature a high concentration of nutrients for the calories they contain, we created a Food Rating System. This system allows us to highlight the foods that are especially rich in particular nutrients. The following chart shows the World's Healthiest Foods that are either an excellent, very good, or good source of vitamin A. Next to each food name, you'll find the serving size we used to calculate the food's nutrient composition, the calories contained in the serving, the amount of vitamin A contained in one serving size of the food, the percent Daily Value (DV%) that this amount represents, the nutrient density that we calculated for this food and nutrient, and the rating we established in our rating system. For most of our nutrient ratings, we adopted the government standards for food labeling that are found in the U.S. Food and Drug Administration's "Reference Values for Nutrition Labeling." Read more background information and details of our rating system.

World's Healthiest Foods ranked as quality sources of vitamin A						
Food	Serving Size	Cals	Amount (mcg RAE)	DRI/DV (%)	Nutrient Density	World's Healthiest Foods Rating
Sweet Potato	1 cup	180.0	1921.80	214	21.4	excellent
Carrots	1 cup	50.0	1019.07	113	40.7	excellent
Spinach	1 cup	41.4	943.29	105	45.6	excellent
Kale	1 cup	36.4	885.36	98	48.6	excellent
Mustard Greens	1 cup	36.4	865.90	96	47.6	excellent

Collard Greens	1 cup	62.7	722.00	80	23.0	excellent
Beet Greens	1 cup	38.9	551.09	61	28.3	excellent
Turnip Greens	1 cup	28.8	549.00	61	38.1	excellent
Swiss Chard	1 cup	35.0	535.85	60	30.6	excellent
Winter Squash	1 cup	75.8	535.36	59	14.1	excellent
Romaine Lettuce	2 cups	16.0	409.37	45	51.2	excellent
Bok Choy	1 cup	20.4	361.16	40	35.4	excellent
Cantaloupe	1 cup	54.4	270.56	30	9.9	excellent
Bell Peppers	1 cup	28.5	144.03	16	10.1	excellent
Parsley	0.50 cup	10.9	128.04	14	23.4	excellent
Broccoli	1 cup	54.6	120.74	13	4.4	very good
Asparagus	1 cup	39.6	90.54	10	4.6	very good
Sea Vegetables	1 TBS	10.8	81.05	9	14.9	very good
Chili Peppers	2 tsp	15.2	80.05	9	10.5	very good
Tomatoes	1 cup	32.4	74.97	8	4.6	very good
Basil	0.50 cup	4.9	55.91	6	22.9	very good
Papaya	1 medium	118.7	131.10	15	2.2	good
Shrimp	4 oz	134.9	102.06	11	1.5	good
Eggs	1 each	77.5	74.50	8	1.9	good
Brussels Sprouts	1 cup	56.2	60.45	7	2.2	good
Grapefruit	0.50 medium	41.0	59.33	7	2.9	good
Cow's milk	4 oz	74.4	56.12	6	1.5	good
Green Beans	1 cup	43.8	43.75	5	2.0	good
Watermelon	1 cup	45.6	43.24	5	1.9	good
Leeks	1 cup	32.2	42.22	5	2.6	good
Apricot	1 whole	16.8	33.70	4	4.0	good
Cilantro	0.50 cup	1.8	26.99	3	29.3	good
Celery	1 cup	16.2	22.67	3	2.8	good

World's Healthiest Foods Rating	Rule
excellent	DRI/DV>=75% OR Density>=7.6 AND DRI/DV>=10%
very good	DRI/DV>=50% OR Density>=3.4 AND DRI/DV>=5%
good	DRI/DV>=25% OR Density>=1.5 AND DRI/DV>=2.5%

Impact of Cooking, Storage and Processing

How do cooking, storage, or processing affect vitamin A?

Retinoid Forms

Preformed vitamin A is relatively stable in the animal foods that contain it. Ordinary handling, storage, and cooking methods for these foods will usually be sufficient to preserve the content of preformed vitamin A. (Most preformed vitamin A is found in the form of retinyl esters.)

In the case of milk, preformed vitamin A in the form of retinyl palmitate has been added to the milk based on U.S. Food and Drug Administration (FDA) fortification requirements. The vitamin A in fortified milk can be damaged by sunlight. In research studies, about 8-31% of the retinyl palmitate in fortified milk is lost following one day of sunlight exposure. As long as milk is stored in the refrigerator in an opaque container (either darkly tinted green or brown glass, or thick solid-color plastic, or waxed cardboard), loss of retinyl palmitate from light exposure should be negligible. (Due to the light sensitivity of retinyl palmitate, we do not recommend packaging in clear glass or clear plastic.)

Carotenoid Forms

The jury is still out regarding the impact of cooking and processing on carotenoids in food. High-carotenoid foods like carrots typically have the vast majority of their carotenoids occurring in *all-trans* form. While this form can provide excellent health support, it is not as readily available to the bloodstream or to our cells as another form called the *cis* form. The cooking of a plant food decreases the total amount of *all-trans* carotenoids found in the food, but it also increases conversion of many *all-trans* carotenoids into their more available *cis* form. As a net result, some studies show better support of carotenoid levels in the blood after consumption of a cooked plant food product (like tomato paste) than a non-cooked plant food product (like fresh tomatoes). In the case of tomatoes, the carotenoid of greatest interest has been lycopene, and several studies have shown better support of blood lycopene levels from cooked and processed tomato products versus fresh tomatoes. However, other factors may have played an important role here, including the breaking apart of cells in the tomato during processing. The crushing of the tomato cells may have made the cell contents more readily available for digestion and metabolism and thereby improved blood levels of tomato constituents, including lycopene. If this sequence of events played a key role, it gives all of us a very good reason to eat slowly and do an outstanding job chewing our food (including tomatoes). Thorough chewing could accomplish the same result as industrial processing, i.e., breaking open of most tomato cells and providing us with easier access to their nutrients.

Retinoid and Carotenoid Forms

Preliminary research has shown an unwanted impact of food irradiation on both retinoid form and carotenoid form vitamin A. At least one researcher has found a decrease of about 12% in total vitamin A content of chicken feed following irradiation at 20 kGy (kilogray). In this same study, the decrease in beta-carotene following irradiation was approximately 25%. We would like to note that there is very little research at this point on the nutrient impact of commercial food irradiation, and that the jury is still out on the impact of this food practice on vitamin A quantity and/or quality.

Risk of Dietary Deficiency

What food practices might lead to a dietary deficiency of vitamin A?

Retinoid Forms

In the United States, about two-thirds of all vitamin A intake from food comes in the form of retinyl esters found in animal products. Butter, cheese, eggs, and organ meats like liver are among the top 10 sources of vitamin A for U.S. adults. Persons who seldom consume any of these foods may be a greater risk of vitamin A deficiency.

One plant-based group of products - the ready-to-eat cereals - are also found within the top 10 sources of vitamin A retinoids because these cereals have often been fortified with vitamin A in the form of retinyl palmitate. The vitamin A in fortified cereals is very likely to have been obtained from a synthetic, non-animal source. However, since it is possible for this vitamin A to have be derived from an animal source, persons who are trying to avoid animal products should contact the cereal manufacturer to make sure that the cereal's retinyl palmitate was produced synthetically. .

Outside of the Unites States, dietary deficiency of vitamin A in its retinoid form is common in many non-industrialized countries, and it is associated with the high incidence of blindness, viral infections, and child mortality.

Carotenoid Forms

Carrots, tomatoes, leafy greens, sweet potatoes, and margarines colored with beta-carotene are found in the top 10 provitamin A-containing foods in the U.S. However, since U.S. adults eat relatively small amounts of vegetables in general, foods containing provitamin A in carotenoid form only account for about one-third of all dietary intake of vitamin A.

U.S. adults who take vitamin A supplements have a much lower rate of deficiency than non-supplement users. However, even when vitamin A from food and supplements is added together, about one-third of all U.S. adults still fail to get the vitamin A they need.

If regular intake of green leafy vegetables or brightly orange- or red-colored vegetables like carrots, tomatoes, sweet potatoes, or red bell peppers in not part of your meal plan, your risk of carotenoid deficiency is increased. Similarly, if you do not regularly consume orange-, red- or pink-colored fruits like watermelon, cantaloupe, papaya, and pink grapefruit, you are also likely to have increased risk of carotenoid deficiency. If these types of vegetables and fruits are both missing from your routine diet, you'll need to add foods from these groups if you want to lower your chances of overall vitamin A deficiency.

One final deficiency note: recent research has shown a relationship between very low birthweight infants (LVBW) and deficient vitamin A intake by the mother. Since these studies looked at blood levels of retinol in the mothers rather than their food intake, we don't know whether low blood levels were the result of poor carotenoid intake from plant foods, poor retinoid intake from animal foods, or a combination of the two. If you're a woman who is considering pregnancy or who is already pregnant, it's especially important consume foods that are rich in vitamin A. These foods could be plant foods rich in provitamin A, animal foods rich in preformed vitamin A, or both.

Other Circumstances that Might Contribute to Deficiency

What other circumstances might contribute to a deficiency of vitamin A?

Both Retinoid and Carotenoid Forms

Since carotenoids and retinoids are fat-soluble nutrients, vitamin A deficiencies involving either carotenoids or retinoids may be caused by a diet that is extremely low in fat and/or the presence of medical conditions that cause a reduction in the ability to absorb dietary fat, such as pancreatic enzyme deficiency, Crohn's disease, celiac sprue, cystic fibrosis, surgical removal of part or all of the stomach, gall bladder disease, and liver disease.

In addition, chronic diarrhea caused by gastrointestinal infections and/or intestinal parasites may contribute to deficiency of vitamin A in either carotenoid or retinoid forms. Viral infections, including the measles, can decrease retinoid-form vitamin A. In addition, exposure to certain toxic chemicals (for example, polybrominated biphenyls and dioxins) can enhance the breakdown of retinoid-form vitamin A by the liver.

In this section about "Other Circumstances That Might Contribute to Deficiency," it's also important to remember that while carotenoid forms of vitamin A can be effectively converted into retinoid forms inside the bodies of many individuals, this conversion process does not always take place in the way that we would like. Many different factors can contribute to problems with conversion of carotenoids into retinoids. These factors include: a person's inherited genetic tendencies; digestive problems; bacterial imbalances in the digestive tract; excessive use of alcohol; smoking; excessive exposure to toxic chemicals; imbalanced intake of vitamin A and vitamin D as a result of high-dose supplementation; and the use of certain over-the-counter and/or prescription medications.

Inadequate intake of protein can also contributes to retinoid-form vitamin A deficiency (see further explanation in the section on Nutrient Interactions).

Relationship with Other Nutrients

What relationship does vitamin A have to other nutrients?

Retinoid Forms

The transport and utilization of vitamin A is dependent upon several vitamin A binding proteins. Because a sufficient dietary intake of protein is required for the manufacture of these binding proteins, inadequate protein intake may result in vitamin A deficiency. In addition, adequate intake of dietary fat and zinc is necessary for the absorption and utilization of vitamin A.

The relationship between retinoid forms of vitamin A and vitamin D status has become an area of special research interest. Recent studies suggest that effects of vitamin D deficiency are worsened by high supplemental intake of vitamin A (in retinoid form). Preliminary studies have shown that when blood levels of vitamin D fall below 50 nM/L (nanomoles per liter), higher supplemental intake of retinol (defined as intake above 2,000 micrograms per day) can worsen problems related to vitamin D deficiency (like bone health). After being consumed in retinol form, vitamin A can be converted by the body into retinoic acid. This retinoid acid, in turn, can stimulate formation and activity of osteoclast cells that then work to remove minerals from bone. Similarly, high doses of retinoic acid also seem to be able to suppress the activity of osteoblast cells, which help deposit minerals into the bone. We'd like highlight the fact that all of these studies on vitamin A and vitamin D involve dose levels of retinoid-form vitamin A not available from food but only from supplements. But if you're among the 34% of all U.S. adults who take supplements containing both vitamin A (in retinoid form) and vitamin D, you may want to consult with a healthcare practitioner about the best ratio of vitamin A and vitamin D for you.

Alongside of this research trend showing exacerbation of vitamin D deficiency following higher intake of supplemental vitamin A is a second research trend showing the *helpfulness* of vitamin A in support of vitamin D metabolism. This second

research trend has made it clear that receptors on our cell membranes for vitamin A (called retinoid X receptors, or RXR) and receptors on our cell membranes for vitamin D (called VDR receptors) actually combine in our cells to produce an VDR/RXR form. (In more technical terms, vitamin A is said to "recruit coactivators" that are needed for expression of vitamin D receptors, and the form of vitamin A needed to assist with vitamin D metabolism in this situation is 9-cis-retinoic acid.) We'll need many future research studies to eventually clarify the relationships between vitamin A and vitamin D, and the exact ramifications for our food choices.

Like its potential interference with vitamin D metabolism, excess retinoid-form vitamin A may also interfere with the metabolism of vitamin K, a fat-soluble vitamin necessary for blood clotting. Like the vitamin A-vitamin D relationship, however, "excess" in this case does not apply to the amount of retinoid-form vitamin A provided by everyday amounts of animal food.

Carotenoid Forms

Recent studies have shown the ability of beta-carotene to improve the availability of two minerals—iron and zinc—from grains. In one lab study, the addition of 2.5 grams of cooked carrot containing 200 micrograms of beta-carotene to a 10-gram portion of cooked rice resulted in a 50% increase in the availability of iron from the rice. In everyday practice, you would need to consume one medium-sized cooked carrot (about 50 grams) along with each cup of cooked rice (about 195 grams) in order to achieve this same nutrient ratio. Similarly, this same addition of beta-carotene was able to increase the availability of zinc in the cooked rice by about 35-40%. The authors of this study speculated that beta-carotene may have been able to form a complex with the minerals to help maintain their solubility and also to help prevent their getting bound together with phytates in rice that would otherwise be able to lower their absorption. While this study was lab-based and not conducted on real people eating real food, we look forward to future studies that may show the ability of beta-carotene content in our plant foods to improve the availability of minerals in those foods like iron and zinc.

Risk of dietary Toxicity

What food practices might lead to a dietary toxicity of vitamin A?

Retinoid Forms

It is almost impossible for ordinary intake of animal foods to result in vitamin A toxicity. Foods simply do not contain enough preformed vitamin A to expose us to toxicity-producing amounts.

Here are some numbers to provide you with a concrete example. When chronic vitamin A toxicity occurs, it typically involves many months of daily intake of vitamin A in retinoid form in amounts exceeding 14,000 IU (4,200 mcg RE) in children and 25,000 IU (7,500 mcg RE) in adults. Let's compare that amount to the largest amounts found in food. At 135 mcg RE of retinol per cup, cow's milk is the animal food on our WHFoods list that ranks highest in retinol content. As you can see, an adult would have to consume over 55 times this amount every day over a period of several months in order to reach the toxicity level described above.

While vitamin A toxicity can be a problem for our health, it comes from improper use of retinoid-containing supplements, not from our diet. Most causes of vitamin A toxicity are due to accidental ingestion of supplemental doses exceeding 660,000 IU (200,000 mcg retinol equivalents) and 330,000 IU (100,000 mcg retinol equivalents) by adults and children, respectively.

In 2000 the National Academy of Sciences (NAS) set Tolerable Upper Intake Levels (ULs) for preformed vitamin A. These recommendations were designed to help prevent excessive amounts of supplemental intake by the general public, not to discourage intake of foods high in retinoid forms of vitamin A. Here were the recommendations of the NAS for maximal intake of retinoid-form vitamin A

- Children 3 years or younger, 600 micrograms (2,000 IU) of preformed vitamin A (retinol) per day
- Children 4-8 years, 900 micrograms (3,000 IU) of preformed vitamin A (retinol) per day
- Children 9-14 years, 1,700 micrograms (5,666 IU) of preformed vitamin A (retinol) per day
- Teenagers 14-18 years, 2,800 mcg (9,333 IU) of preformed vitamin A (retinol) per day
- Adults 19 years and older, 3,000 mcg (10,000 IU) of preformed vitamin A (retinol) per day
- Pregnant or lactating women 18 years or younger, 2,800 mcg (9,333 IU) of preformed vitamin A (retinol) per day
- Pregnant or lactating women 19 years or older, 3,000 mcg (10,000 IU) of preformed vitamin A (retinol) per day

Carotenoid Forms

A telltale sign of excessive consumption of beta-carotene is a yellowish discoloration of the skin, most often occurring in the palms of the hands and soles of the feet. This condition is called carotenodermia and is generally considered to be reversible and harmless. Excessive consumption of the carotenoid lycopene can cause a deep orange discoloration of the skin. Like carotenodermia, lycopenodermia is generally considered reversible and harmless.

High intake of carotenoid-containing foods or supplements is not associated with any specific toxic side effects. As a result, the Institute of Medicine at the National Academy of Sciences did not establish a Tolerable Upper Intake Level (UL) for carotenoids when it reviewed these compounds in 2000.

Disease Checklist

What diseases might have a special connection with vitamin A?

Retinoid forms of vitamin A may play a role in the prevention and/or treatment of the following health conditions:

- Acne
- AIDS
- Alcoholism
- Atopic dermatitis
- Cataracts
- Cervical dysplasia
- Cystic Fibrosis
- Diabetes
- Dry Eyes
- Fibrocycstic breast disease
- Hyperkeratosis
- Impotence (Lack of sperm production)
- Inflammaotory bowel disease
- Kaposi's sarcoma
- Leukoplakia
- Measles
- Osteoarthritis
- Otitis media (ear infection)
- Poor vision
- Premature Delivery
- Psoriasis
- Thyroid disorders
- Ulcers
- Vaginitis
- Varicose veins
- Viral infections

Carotenoid forms of vitamin A may play a role in the prevention and/or treatment of the following health conditions:

- Acquired Immunodeficiency Syndrome (AIDS)
- Age-related macular degeneration
- Angina pectoris
- Asthma
- Cataracts
- Cervical cancer
- Cervical dysplasia
- Chlamydial infection
- Heart disease
- Laryngeal cancer (cancer of the larynx)
- Lung cancer
- Male and female infertility
- Osteoarthritis
- Photosensitivity
- Pneumonia
- Prostate cancer

- Rheumatoid arthritis
- Skin cancer
- Vaginal candidiasis

Public Health Recommendations

What are current public health recommendations for vitamin A?

Public health recommendations for vitamin A can be confusing due to units of measurement. Food and supplement labels present vitamin A content in terms of the Daily Values (DVs). The DVs were established in 1993 by the U.S. Food and Drug Administration (FDA) and are measured in IU (International Units). However, about 20 years earlier (in 1974), the National Academy of Sciences (NAS) had already established its own set of public health recommendations, setting vitamin A requirements in terms of micrograms retinol equivalents (micrograms RE, or mcg RE). In 2001, the NAS changed this measurement standard from mcg RE to mcg RAE (micrograms retinol activity equivalents). Today, you might find public health recommendations using all three units of measurement: RE, RAE, and IU.

If you need to make conversions between these different units of measurement for vitamin A, here are the rules you must follow:

In the RE and RAE measurement systems, 1 microgram of retinol is equivalent to 1 RAE/1 RE while 1 RE is equal to 6 micrograms of beta-carotene or 12 micrograms of alpha-carotene or beta-cryptoxanthin. Additionally, 1 RAE is equal to 12 micrograms of beta-carotene or 24 micrograms of alpha-carotene or beta-cryptoxanthin, and 1 IU is equal to 0.3 micrograms of retinol, 0.6 micrograms of beta-carotene, or 1.2 micrograms of alpha-carotene or beta-cryptoxanthin. (Please note that the word "microgram" is commonly abbreviated as "mcg.")

When converting between these two units of measure, 1 retinol equivalent (or RE) is equal to 3.33 International Units (or IU) of preformed vitamin A.

In 2000, the National Academy of Sciences established the following Adequate Intake (AI) levels for consumption of vitamin A by infants:

- Males and females 0-6 months: 400 mcg RAE (1,333 IU)
- Males and females 7-12 months: 500 mcg RAE (1,666 IU)

In 2000, the National Academy of Sciences established the following Recommended Dietary Allowances (RDAs) for consumption of vitamin A by children and adults. (Please note that the acronym "RAE" used below stands for Retinol Activity Equivalents, and the abbreviation "mcg" stands for micrograms.)

- Males and females, 1-3 years: 300 mcg RAE (1,000 IU)
- Males and females, 4-8 years: 400 mcg RAE (1,333 IU)
- Males and females, 9-13 years: 600 mcg RAE (2,000 IU)
- Males, 14 years and older: 900 mcg RAE (3,000 IU)
- Females, 14 years and older: 700 mcg RAE (2,333 IU)

In 2000, the National Academy of Sciences established the following Estimated Average Requirements (EARs) for consumption of vitamin A by pregnant and lactating women:

- Pregnant women less than 18 years of age: 750 mcg RAE (2,500 IU)
- Pregnant women 19 years and older 770 mcg RAE (2,567 IU)
- Lactating women, 18 years or younger: 1,200 mcg RAE (4,000 IU)
- Lactating women, 19 years or older: 1,300 mcg RAE (4,333 IU)

The Institute of Medicine set Tolerable Upper Intake Levels (ULs) for **preformed** vitamin A as follows:

- Children 3 years or younger, 600 micrograms (2,000 IU) of preformed vitamin A (retinol) per day
- Children 4-8 years, 900 micrograms (3,000 IU) of preformed vitamin A (retinol) per day
- Children 9-14 years, 1,700 micrograms (5,666 IU) of preformed vitamin A (retinol) per day
- Teenagers 14-18 years, 2,800 mcg (9,333 IU) of preformed vitamin A (retinol) per day
- Adults 19 years and older, 3,000 mcg (10,000 IU) of preformed vitamin A (retinol) per day
- Pregnant or lactating women 18 years or younger, 2,800 mcg (9,333 IU) of preformed vitamin A (retinol) per day
- Pregnant or lactating women 19 years or older, 3,000 mcg (10,000 IU) of preformed vitamin A (retinol) per day

The Daily Value (DV) for vitamin A - as updated in 2008 by the U.S. Food and Drug Administration - is 5,000 IU. This DV standard is the one that you currently see on food labels, and it is based on a 2,000 calorie diet. The 5,000 IU Daily Value also translates into 1,500 mcg RAE of vitamin A.

For our WHFoods standard, we chose the National Academy of Sciences (NAS) most recent DRI recommendation of 900 mcg RAE of vitamin A for men 19 years and older. This amount translates into 3,000 IU of vitamin A. Like the NAS, we chose to adopt a standard for total vitamin A in all of its forms, and we did not adopt separate standards for individual forms of vitamin A, for example, total carotenoids or beta-carotene.

For more details on toxicity of preformed vitamin A, please see the Risk of Dietary Toxicity section above.

For more details on toxicity of preformed vitamin A, please see the Toxicity Symptoms section above.

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The World's Healthiest Foods

World's Healthiest Foods rich in vitamin B1		
Food	Cals	DRI/DV
Sunflower Seeds	204	43%
Navy Beans	255	36%
Black Beans	227	35%
Barley	217	33%
Dried Peas	231	31%
Green Peas	116	30%
Lentils	230	28%
Pinto Beans	245	28%
Lima Beans	216	25%
Oats	152	25%

Basic Description

Vitamin B1, also known as thiamin, is classified as a B-complex vitamin. Very small amounts of vitamin B1 are found in virtually all foods, and many commonly eaten foods contain substantial amounts. For example, 50/100 of our WHFoods rank as good, very good, or excellent sources of B1. In this context, it might seem odd that deficiency of vitamin B1 is among the more common nutrient deficiencies in the U.S.

Yet there is a very simple reason for this high risk of deficiency despite the widespread availability of vitamin B1 in foods, and that reason is food processing. Vitamin B1 is among the nutrients most prone to destruction by our modern food production system. At each step along the way, from storage though refining up through cooking, we lose a big portion of the vitamin B1 content of foods. We'll detail this more in the Impact of Cooking, Storage, and Processing section below.

For these reasons, vitamin B1 makes a good case study for the wisdom of the World's Healthiest Foods approach of minimal processing and low impact cooking techniques.

Of the foods listed on our site, we have one excellent source of vitamin B1 (asparagus), 10 very good sources, and 39 good sources. All of the World's Healthiest Foods, with the exceptions of a few spices and sweeteners, contain at least some vitamin B1. We have 61 recipes with more than one quarter of the Dietary Reference Intake (DRI) for vitamin B1. Two examples are Healthy Turkey Salad and Sauteéed Mushrooms With Green Peas.

Role in Health Support

Promotes Energy Production

Like the other B vitamins, B1 is a key player in the production of energy from dietary carbohydrates and fats. In fact, you could easily make the case that vitamin B1 plays the most critical role of all, acting as the gate keeper between the less efficient step of early carbohydrate breakdown and the very energy-rich Krebs' cycle and electron transport chain.

Because of the central role of vitamin B1 to energy metabolism, deficiency of this nutrient impairs nearly every important function in the body. Severe and prolonged vitamin B1 deficiency—rare in the United States—has been reported to affect the nervous system, the heart, and digestive function, among other areas.

Offers Nervous System Support

The brain is one of the most energy hungry tissues in the human body. As such, it shouldn't be a surprise to see vitamin B1 deficiency commonly leading to problems in the nervous system. The only surprise may be that this vitamin has been linked to so many varied conditions, from alcohol-related brain disease to Alzheimer's and Parkinson's diseases.

In addition to its role in energy production, vitamin B1 plays a key role in the structure and integrity of the cells of the brain. If the deficiency is very advanced, or occurs at a critical period of brain development, the damage can be quite severe.

Summary of Food Sources

As a rule of thumb, legumes and vegetables are the richest whole food sources of vitamin B1. Nuts and seeds can also be concentrated in vitamin B1. Below are some further details about vitamin B1 and the World's Healthiest Foods.

Many of the World's Healthiest vegetables rank as good sources of vitamin B1. These vegetables include broccoli, onions, green beans, summer squash, carrots, kale, and tomatoes. More nutrient-rich and ranking as very good sources of vitamin B1 are green peas, beet greens, Brussels sprouts, spinach, cabbage, eggplant, romaine lettuce, and crimini mushrooms. And topping our WHFoods list as an excellent source of B1 is asparagus.

Very good sources of vitamin B1 in the seeds group include sunflower seeds and flax seeds. Good sources in the legume group include navy, black, pinto, lima, and kidney beans, as well as lentils and dried peas.

Introduction to Nutrient Rating System Chart

In order to better help you identify foods that feature a high concentration of nutrients for the calories they contain, we created a Food Rating System. This system allows us to highlight the foods that are especially rich in particular nutrients. The following chart shows the World's Healthiest Foods that are either an excellent, very good, or good source of vitamin B1. Next to each food name, you'll find the serving size we used to calculate the food's nutrient composition, the calories contained in the serving, the amount of vitamin B1 contained in one serving size of the food, the percent Daily Value (DV%) that this amount represents, the nutrient density that we calculated for this food and nutrient, and the rating we established in our rating system. For most of our nutrient ratings, we adopted the government standards for food labeling that are found in the U.S. Food and Drug Administration's "Reference Values for Nutrition Labeling." Read more background information and details of our rating system.

World's Healthiest Foods ranked as quality sources of vitamin B1						
Food	Serving Size	Cals	Amount (mg)	DRI/DV (%)	Nutrient Density	World's Healthiest Foods Rating
Asparagus	1 cup	39.6	0.29	24	11.0	excellent
Sunflower Seeds	0.25 cup	204.4	0.52	43	3.8	very good
Green Peas	1 cup	115.7	0.36	30	4.7	very good
Flaxseeds	2 TBS	74.8	0.23	19	4.6	very good
Brussels Sprouts	1 cup	56.2	0.17	14	4.5	very good
Beet Greens	1 cup	38.9	0.17	14	6.6	very good
Spinach	1 cup	41.4	0.17	14	6.2	very good
Cabbage	1 cup	43.5	0.11	9	3.8	very good
Eggplant	1 cup	34.6	0.08	7	3.5	very good
Romaine Lettuce	2 cups	16.0	0.07	6	6.6	very good
Mushrooms, Crimini	1 cup	15.8	0.07	6	6.6	very good
Navy Beans	1 cup	254.8	0.43	36	2.5	good
Black Beans	1 cup	227.0	0.42	35	2.8	good
Barley	0.33 cup	217.1	0.40	33	2.8	good
Dried Peas	1 cup	231.3	0.37	31	2.4	good
Lentils	1 cup	229.7	0.33	28	2.2	good
Pinto Beans	1 cup	244.5	0.33	28	2.0	good
Lima Beans	1 cup	216.2	0.30	25	2.1	good
Oats	0.25 cup	151.7	0.30	25	3.0	good
Sesame Seeds	0.25 cup	206.3	0.28	23	2.0	good
Kidney Beans	1 cup	224.8	0.28	23	1.9	good
Peanuts	0.25 cup	206.9	0.23	19	1.7	good
Sweet Potato	1 cup	180.0	0.21	18	1.8	good
Tofu	4 oz	164.4	0.18	15	1.6	good
Tuna	4 oz	147.4	0.15	13	1.5	good
Pineapple	1 cup	82.5	0.13	11	2.4	good

Oranges	1 medium	61.6	0.11	9	2.7	good
Broccoli	1 cup	54.6	0.10	8	2.7	good
Green Beans	1 cup	43.8	0.09	8	3.1	good
Onions	1 cup	92.4	0.09	8	1.5	good
Collard Greens	1 cup	62.7	0.08	7	1.9	good
Summer Squash	1 cup	36.0	0.08	7	3.3	good
Carrots	1 cup	50.0	0.08	7	2.4	good
Tomatoes	1 cup	32.4	0.07	6	3.2	good
Cantaloupe	1 cup	54.4	0.07	6	1.9	good
Kale	1 cup	36.4	0.07	6	2.9	good
Mustard Greens	1 cup	36.4	0.06	5	2.5	good
Turnip Greens	1 cup	28.8	0.06	5	3.1	good
Swiss Chard	1 cup	35.0	0.06	5	2.6	good
Bok Choy	1 cup	20.4	0.05	4	3.7	good
Watermelon	1 cup	45.6	0.05	4	1.6	good
Bell Peppers	1 cup	28.5	0.05	4	2.6	good
Cauliflower	1 cup	28.5	0.05	4	2.6	good
Grapefruit	0.50 medium	41.0	0.05	4	1.8	good
Garlic	6 cloves	26.8	0.04	3	2.2	good
Parsley	0.50 cup	10.9	0.03	3	4.1	good
Cucumber	1 cup	15.6	0.03	3	2.9	good
Cumin	2 tsp	15.8	0.03	3	2.9	good
Mustard Seeds	2 tsp	20.3	0.03	3	2.2	good
Sea Vegetables	1 TBS	10.8	0.03	3	4.1	good

World's Healthiest Foods Rating	Rule
excellent	DRI/DV>=75% OR Density>=7.6 AND DRI/DV>=10%
very good	DRI/DV>=50% OR Density>=3.4 AND DRI/DV>=5%
good	DRI/DV>=25% OR Density>=1.5 AND DRI/DV>=2.5%

Impact of Cooking, Storage and Processing

Few nutrients have more risk of damage during food processing than B1. It is prone to damage from heat, not entirely stable to storage, and commonly removed from foods in cooking and refining.

Vitamin B1 is prone to destruction by heat. Conventional cooking methods and microwaving can be expected to reduce the vitamin B1 content of food by roughly 20-50%. Prolonged high-temperature roasting may be one of the most problematic cooking methods in this regard. One research group has shown a near total destruction in grains roasted at 300°F (205°C) for one hour.

One of the first health problems to be linked with vitamin B1 deficiency was beriberi. Beriberi is extremely rare in the United States. But from a historical perspective, beriberi was a particularly problematic disease in countries that depended very heavily on intake of rice and who began to polish the outer layers off of the rice prior to cooking. Since B1 was contained in these outer layers, they were polishing off the B1 as well. While few people in the U.S. are likely to get diagnosed with beriberi (primarily because we are not heavily dependent on intake of rice as a source of B1), processed rice and other processed grains are likely to have lost a good amount of B1. Avoiding this situation is one reason we emphasize the importance of whole natural foods.

The value of whole natural foods as sources of B1 is easy to see in our WHFoods recipes. Many of our most vitamin B1-rich recipes—for example, our Mediterranean-Style Salad and Vegetable Appetizer 4—require almost no cooking or processing of ingredients in preparation. Our Mediterranean-Style Salad provides you with 50% of your daily vitamin B1! And our Vegetable Appetizer 4 provides you with 45%.

For more specifics on how to best choose specific foods for optimal nutrient content, visit the "How to Select and Store" content for each food.

Risk of Dietary Deficiency

The risk of dietary deficiency of vitamin B1 in the U.S. is substantial. Nearly 20% of US residents over the age of 2 years fail to reach recommended amounts of dietary vitamin B1 each day.

If that doesn't sound bad enough, the story is actually a bit worse. If it weren't for the "enrichment" of wheat flour in the United States—a process whereby nutrients destroyed by processing are added back into processed wheat—more than half of Americans would fail to reach the DRI standard for vitamin B1. Our U.S. dependence on artificially rich foods as a source of B1 would be greatly reduced if we shifted over to a minimally processed diet based around fresh whole foods.

In a daily diet, if you get at least one serving of legumes and another of seeds, you'll be at least half way to the daily value recommendation for vitamin B1. Adding several servings of vegetables should get you well on your way to the recommended daily total.

As noted above, the recipes featured here at the World's Healthiest Foods tend to be quite rich in vitamin B1. In fact, following our Healthiest Way of Eating Plan provides enough of vitamin B1 over the sample week to exceed the recommended amount as a daily average.

Other Circumstances that Might Contribute to Deficiency

People with heart failure, gastrointestinal disease, and diabetes all have increased risk of vitamin B1 deficiency. In each of these groups, restoring normal vitamin B1 levels may prevent some of the worst complications of disease.

Even in the absence of either of these two diseases, elderly people are at increased risk of vitamin B1 deficiency. This is, at least in part, due to a reduction in the ability to absorb dietary vitamin B1 that occurs. To date, researchers have not been able to conclusively prove why this occurs.

A few foods contain substances that can compromise vitamin B1 nourishment. Most of these would be foods we either don't eat regularly (like raw shellfish and silkworms) or molds that infect foods.

Perhaps the most important and well-known inhibitor of vitamin B1 nutrition in humans, however, is alcohol abuse. Alcoholics use more vitamin B1 in the detoxification of alcohol, often eat less vitamin B1 due to poor dietary habits, have trouble absorbing vitamin B1 in the intestine, and urinate out more of the vitamin. This is an almost perfect scenario for increasing deficiency risk.

Relationship with Other Nutrients

The way vitamins are named is somewhat confusing—some have just letters, and some have a letter and a number. These numbers and letters are sometimes consecutive, and sometimes not.

Historically, the B vitamins are considered part of a complex because originally they were not understood to be multiple different vitamins. In fact, the individual B complex vitamins tend to overlap with and enhance the activity of the others. When the B complex vitamins are all present, they work as a team to help make sure your cells have they energy they need.

Vitamin B1 is a good example of this complex interaction. When other B vitamins become deficient, particularly folic acid and vitamin B12, absorption of vitamin B1 is compromised. In the opposite direction, having severe vitamin B1 deficiency can lead to diarrhea, compromising absorption of other nutrients.

Risk of dietary Toxicity

We have not been able to find any reports of toxicity related to dietary intake of vitamin B1. When supply of the vitamin exceeds our needs, we urinate out the excess. Reflecting the lack of evidence of toxicity, The National Academy of Sciences has not chosen to establish a Tolerable Upper Intake Level (UL) for vitamin B1.

Disease Checklist

- Beri-beri
- Wernicke's encephalopathy
- Congestive Heart Failure
- Diabetes
- Alzheimer's disease
- Pulmonary hypertension
- Liver failure
- Alcoholism
- HIV / AIDS

Public Health Recommendations

In 1998, the Food and Nutrition Board of the National Academy of Sciences established Dietary Reference Intake (DRI) recommendations for vitamin B1. The DRIs included Adequate Intake (AI) recommendations for very young children under one year of age, and Recommended Dietary Allowances (RDAs) for all other individuals. All DRIs for vitamin B1 are summarized below:

- 0-6 months: 0.2 mg
- 6-12 months: 0.3 mg
- 1-3 years: 0.5 mg
- 4-8 years: 0.6 mg
- 9-13 years: 0.9 mg
- 14-18 years, female: 1.0 mg
- 14-18 years, male: 1.2 mg
- 19+ years, female: 1.1 mg
- 19+ years, male: 1.2 mg
- Pregnant women: 1.1 mg
- Lactating women: 1.4 mg

The Daily Value (DV) for vitamin B1 is 1.5 mg per 2000 calories in the diet. This is the value you'll find listed on food labels.

There is no established Tolerable Upper Intake Limit (UL) for vitamin B1.

As our WHFoods recommendation for daily intake of vitamin B1, we chose the Dietary Reference Intake (DRI) level for men 14 and older of 1.2 milligrams. (This level is about 10% higher than the DRI for women 19 and older of 1.1 milligrams, and we chose it to make sure that both men and women would be covered by the guideline.) The Nutrient Richness Charts on this page use this as the comparison standard as does any food Nutrient Richness Chart where you would see vitamin B1 noted. We chose this as the most recent estimate of vitamin B1 requirement, and the value that best reflects current scientific understanding.

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The World's Healthiest Foods

World's Healthiest Foods rich in vitamin B12		
Food	Cals	DRI/DV
Sardines	189	338%
Salmon	158	236%
Tuna	147	111%
Cod	96	109%
Lamb	310	105%
Scallops	126	102%
Shrimp	135	78%
Beef	175	60%
Yogurt	149	38%
Cow's milk	74	23%

Basic Description

Vitamin B12, as the name implies, is part of the B complex of vitamins. Like the other B vitamins, it is involved in energy metabolism and other related biological processes.

However, that is where the similarity ends. The list of things that are unique about this vitamin is long, and includes the following facts:

- Most B vitamins do not store well, but several years' worth of vitamin B12 can be stored in your body
- Most B vitamins can be found in a wide variety of plant and animal foods, but since no plant or animal can make vitamin B12 (only microorganisms like fungi and bacteria can do that), it is typically only animal foods that contain B12 since plants cannot make or store this vitamin. However, mushrooms (since they are themselves fungi) often contain B12, as do fermented plant foods like tempeh or miso since they have been produced with the help of microorganisms. Most B vitamins are relatively small and have a fairly simple chemical structure, while vitamin B12 is larger and more complex.
- Most B vitamins are more easily absorbed than vitamin B12,which has more complicated requirements for absorption.
- In terms of physical amount, vitamin B12 has the lowest daily requirement of all the B vitamins, and it is needed in about 1/1000th the amount of some other B vitamins.
- Vitamin B12 is the only vitamin that contains a metal element (cobalt). In fact, the cobalt contained in B12 is the reason that this vitamin goes by the chemical name cobalamin.

As the list above implies, optimal intake of vitamin B12 can sometimes be a challenge in human nutrition. Even though U.S. adults ages 20 and older average well above the Dietary Reference Intake (DRI) for B12, there are still subgroups within the U.S. that are more commonly at risk of B12 deficiency. For example, adults 51 and older can be at greater risk of B12 deficiency, presumably in relationship to decreased dietary intake and/or compromised digestive function.

The style of diet that you choose can have an major impact on your B12 nourishment. If you regularly consume land animal foods and fish in your meal plan, B12 intake is not very likely to be a problem. If you regularly consume fish but avoid land animal foods, B12 is still relatively unlikely to be a problem. With no fish or land animal foods in your routine diet, however, you are left with some fairly specific food sources of B12, namely, fermented foods such as tempeh and fungi (including mushrooms). We'll give you some practical steps for obtaining B12 nourishment in the Food Sources section.

We list eight excellent sources of vitamin B12 on World's Healthiest Foods. We also have three very good and four good sources of the vitamin. Although the number of good sources is smaller than for many foods, this should be plenty to ensure a strong supply of this critical nutrient.

Role in Health Support

Cardiovascular Support

Vitamin B12 plays several important roles in keeping our cardiovascular system on track. The first of these roles involves production of red blood cells. Red blood cells are critical for transporting oxygen throughout our bloodstream, and the oxygen-carrying pigment in the center of our red blood cells is called hemoglobin. A key building block for hemoglobin is a compound called succinylCoA, and without enough vitamin B12, we simply cannot make enough of this building block. (Methylmalonyl CoA mutase is the enzyme that allows this process to take place, and it only functions with the help of B12 in the form of adenosylcobalamin.)

The fact that B12 plays such a key role in red blood cell production means that deficiency of this vitamin can actually cause a form of anemia called B12 deficiency anemia. However, this form of anemia is relatively rare. Often, when it appears to occur, it is actually a by-product of pernicious anemia in which immune system antibodies interfere with the production or function of intrinsic factor (IF). IF is a glycoprotein produced by specialized stomach cells called parietal cells and it is required for proper metabolism of vitamin B12.

A second important role for B12 in cardiovascular support involves prevention of excessive homocysteine build-up. A long list of cardiovascular diseases have been associated with excessive accumulation of homocysteine in the bloodstream, including coronary heart disease, peripheral vascular disease, and stroke. Vitamin B12 helps normalize levels of homocysteine in the blood by allowing conversion of homocysteine to methionine. (This conversion process takes place through activity of the enzyme methionine synthase.)

DNA Production

Vitamin B12 is a necessary co-factor for the production of DNA, the genetic material that acts as the backbone of all life. This process requires folate and vitamin B6 as well, and disruptions of any of these nutrients can lead to problems.

The diagnosis of vitamin B12 deficiency is often dependent on problems with DNA production. When vitamin B12 is low, normally rapidly dividing blood cells are not able to effectively reproduce their DNA, leading to abnormally big cells. This phenomenon, called macrocytosis, is often the first way doctors suspect problems with the vitamin.

Brain and Nervous System Health

Along with the heart, liver, muscles, and kidneys, the brain is an organ that utilizes a large amount of energy in a form called aerobic energy. Aerobic energy means oxygen-requiring energy production in specialized cell parts called mitochondria. As described earlier in the Cardiovascular Support section, one role that B12 plays is maintenance of hemoglobin in red blood cells to allow successful transport of oxygen. This process is especially important in brain health.

Another role of B12 described in the Cardiovascular Support section was prevention of excessive homocysteine build-up in the blood through conversion of homocysteine to methione. However, one aspect of this process not described earlier is the simultaneous recycling of a molecule called SAMe (S-adenosylmethionine) that takes place along with homocysteine conversion. SAMe has sometimes been referred to as the "universal methyl donor" because of its unique ability to provide special chemical groups—called methyl groups—in many different places where they are needed. One such place is the brain and nervous system, where movement of methyl groups is a key process. Some of the nervous system messengers (neurotransmitters) cannot be produced without the help of enzymes called methyltransferases, and these enzymes in turn cannot be produced without the availability of methyl groups. This area of methyl metabolism is another key way in which vitamin B12 plays a major role in the health of our brain and nervous system.

These nervous system connections to B12 help explain some of the clinical symptoms associated with B12 deficiency. When levels of vitamin B12 get very low, nerve damage can ensue. The insulation sheath around nerve fibers begins to break down, making it harder for signals to get to more distant areas of the body (called peripheral areas). As you might guess, symptoms first become apparent in the hands and feet. While the exact mechanisms are not fully understood, researchers know that severe B12 deficiency can cause these "peripheral neuropathies" and that restoring optimal supplies of B12 can keep these problems from becoming more severe.

Support of Energy Metabolism

While mentioned earlier, it's important to underscore the role of B12 in support of oxygen-based energy production (called aerobic energy). At the heart of this process is a metabolic cycle called the citric acid cycle and included within this cycle is a molecule called succinyl-coA. Since vitamin B12 is important for maintaining proper supplies of succinyl-coA in the citric acid cycle, it is important for supporting all aerobic energy metabolism.

Other Potential Health Benefits

Still under debate by researchers is the exact role of B12 in support of bone health. On the one hand, B12 deficiency appears to be associated with increased risk of osteoporosis. This connection involves the positive role of B12 (in several of its cobalamin forms) in supporting the activity of the osteoblast (bone-forming) cells. At the same time, B12 also appears to help regulate activity of tumor necrosis factor (TNF). TNF overactivity can result in too much bone breakdown and remodeling by a second type of bone cells called osteoclasts. Too much osteoclast activity—regardless of the reason for its occurrence—is also associated with increased risk of osteoporosis. Despite these logical connections between B12 deficiency and osteoporosis risk, however, actual research findings are inconsistent in making the B12 connection to bone status.

Summary of Food Sources

Microorganisms—and especially bacteria and fungi—are the only organisms definitively known to produce vitamin B12. There has been longstanding debate over algal production of B12, which includes debate over the potential role of sea vegetables to provide B12 (as well as debate over dietary supplements like spirulina). However, we interpret the research in this area to show that sea vegetables cannot be counted on for B12 support, not because there is no possibility of B12 production in sea vegetables, but because the form of B12 in sea vegetables is not a usable vitamin form.

Even though land animals and fish cannot make vitamin B12 in their cells, they are often able to save up B12 produced by bacteria and concentrate it in their cells. For this reason, many land animal foods and many seafoods are nutrient-rich in B12. In fact, all but one of our WHFoods ranked sources of B12 come from animal foods or fish. Because plants do not concentrate or utilize vitamin B12 in the same way as animals, plant foods do not become nutrient-rich in B12 unless they have been fermented (like the fermentation of soybeans into tempeh) by B12-producing bacteria or fungi. Excluded from this statement are fungi (for example, mushrooms) since scientists classify them in their own separate category from plants. But if we adopt a less technical perspective and include mushrooms as plant foods, they would also have to be included as sources of B12. At WHFoods, crimini mushrooms are our only ranked non-animal derived food source for B12.

Our recommended daily intake level for B12 is 2.4 micrograms, and one serving of any of the following WHFoods will provide you with 100% or more of this amount: sardines, salmon, tuna, cod, lamb, or scallops. You'll get over 50% with a single serving of beef or shrimp, about one-third of the daily amount from one cup of yogurt, and between 10-25% from one serving of cheese, chicken, turkey, eggs, or cow's milk.

In contrast with these animal and fish foods, one cup of crimini mushrooms will only provide you with about 3% of the daily recommend amount. This relatively low contribution from mushrooms (a non-animal food) raises the important question of B12 nourishment for individuals who don't regularly consume animal foods or fish. In the broadest sense, individuals who focus primarily on plant foods in their meal plan are often referred to as "vegetarians." However, this term can have a variety of different meanings. "Pesca-vegetarians," for example, consume fish along with plant foods. "Lacto-vegetarians" consume dairy foods along with plants foods. "Lacto-ovo vegetarians" consume not only dairy foods but also eggs along with plant foods. If a person eats plant foods exclusively, the term usually used to describe his or her meal plan is "vegan." Most healthcare providers—including most nutritionists—currently recommend that persons who exclusively consume plant foods take steps to ensure their B12 nourishment by adding foods fortified with B12 or B12-containing supplements to their daily routine. As a general rule, we support this approach, although we realize that there can be exceptions.

Nutritional yeast grown on a molasses medium is an example of a food-based quasi-supplement that would provide a vegan source of vitamin B12. One widely available brand has more than twice the Dietary Reference Intake (DRI) for B12 in one and one-half tablespoons of yeast. Not all nutritional yeasts are rich in vitamin B12, however, and you'll need to check labels for details.

Before leaving the topic of B12 and food sources, we want to go one step further in explaining some ongoing speculation about the relationship between B12, bacteria, and human nutrition. As described earlier, bacteria and other microorganisms are the only life forms that can be described as definitively able to produce B12. Interestingly, however, research studies have shown that bacteria capable of producing B12 can live inside our human intestinal tract. (One example of a bacterium known to produce B12 and also able to colonize parts of our digestive tract is *Propionibacterium shermanii*.) Furthermore, it seems likely that B12-producing bacteria are able reside in the very last segment of our small intestine known as the terminal ileum.The terminal ileum is especially important for vitamin B12 nourishment since it is the primary site for B12 absorption. In this last segment of our small intestine, however, there aren't nearly as many bacteria as are present in our large intestine. (We're talking about a minimum of 10,000 times less, and probably more like one million times less.) So exactly how much B12 contribution could potentially be made by B12-producing bacteria in the terminal ileum is an open question. While we don't see any justification for relying on bacterial production of B12 in our intestines as a source of this vitamin, it is also impossible for us to totally rule out this possible pathway for B12 nourishment and hopefully we will get some further clarification here in future research.

Nutritional yeast grown on a molasses medium is an example of a food-based quasi-supplement approach that would provide a vegan source of vitamin B12. One widely available brand has more than twice the Recommended Dietary Allowance (RDA) for B12 in one and one-half tablespoons of yeast. Note that not all nutritional yeasts are rich in vitamin B12, and that you'll need to check labels for details.

The National Academy of Sciences currently recommends that people over the age of 50 receive much of their vitamin B12 from supplements or fortified foods. Currently, about 40% of the vitamin B12 that Americans eat comes from these non-food sources. In addition to the fortified yeast discussed above, soy products and breakfast cereals often contain this type of added vitamin B12.

Introduction to Nutrient Rating System Chart

In order to better help you identify foods that feature a high concentration of nutrients for the calories they contain, we created a Food Rating System. This system allows us to highlight the foods that are especially rich in particular nutrients. The following chart shows the World's Healthiest Foods that are either an excellent, very good, or good source of vitamin B12. Next to each food name, you'll find the serving size we used to calculate the food's nutrient composition, the calories contained in the serving, the amount of vitamin B12 contained in one serving size of the food, the percent Daily Value (DV%) that this amount represents, the nutrient density that we calculated for this food and nutrient, and the rating we established in our rating system. For most of our nutrient ratings, we adopted the government standards for food labeling that are found in the U.S. Food and Drug Administration's "Reference Values for Nutrition Labeling." Read more background information and details of our rating system.

World's Healthiest Foods ranked as quality sources of vitamin B12						
Food	**Serving Size**	**Cals**	**Amount (mcg)**	**DRI/DV (%)**	**Nutrient Density**	**World's Healthiest Foods Rating**
Sardines	3.20 oz	188.7	8.11	338	32.2	excellent
Salmon	4 oz	157.6	5.67	236	27.0	excellent
Tuna	4 oz	147.4	2.66	111	13.5	excellent
Cod	4 oz	96.4	2.62	109	20.4	excellent
Lamb	4 oz	310.4	2.51	105	6.1	excellent
Scallops	4 oz	125.9	2.44	102	14.5	excellent
Shrimp	4 oz	134.9	1.88	78	10.4	excellent
Beef	4 oz	175.0	1.44	60	6.2	very good
Yogurt	1 cup	149.4	0.91	38	4.6	very good
Cow's milk	4 oz	74.4	0.55	23	5.5	very good
Eggs	1 each	77.5	0.55	23	5.3	very good
Turkey	4 oz	166.7	0.42	18	1.9	good
Chicken	4 oz	187.1	0.39	16	1.6	good
Cheese	1 oz	114.2	0.24	10	1.6	good
Mushrooms, Crimini	1 cup	15.8	0.07	3	3.3	good

World's Healthiest Foods Rating	Rule
excellent	DRI/DV>=75% OR Density>=7.6 AND DRI/DV>=10%
very good	DRI/DV>=50% OR Density>=3.4 AND DRI/DV>=5%
good	DRI/DV>=25% OR Density>=1.5 AND DRI/DV>=2.5%

Impact of Cooking, Storage and Processing

Even though the structure of vitamin B12 is complicated, it is a relatively stable molecule to storage and cooking. Most of the B12 losses that we have seen from the cooking of B12-rich foods fall into the range of 10-50%. At the 50% end of the spectrum, most of the studies have involved boiling. Since B12 is a water-soluble vitamin, that finding makes sense to us, and it is one of the reasons that we generally prefer steaming over boiling, and when we do boil, it is for a relatively short period of

time. The Healthy Sauté methods and braising methods that we use for fish generally take only 5-10 minutes of cooking time, and the same is true for steaming in recipes where fish are steamed. For meats, we often use a Quick Broil method that only involves dry heat. In short, we believe that you can count on substantial B12 nourishment from our B12-rich foods if you take advantage of our WHFoods cooking methods.

Risk of Dietary Deficiency

For most U.S. adults, the risk of dietary deficiency of vitamin B12 is quite low. The median intake of vitamin B12 in the United States and Canada has been variously estimated between 3 and 7 mcg per day. As such, most people are getting plenty of this vitamin to prevent deficiency.

The only group where we see any substantial risk of dietary vitamin B12 deficiency is in strict vegans (who consume no animal or fish foods whatsoever). In a group of 232 British vegans, most of whom were younger than age 50, a little more than half had biochemical evidence of dietary vitamin B12 deficiency. The deficiency risk was nearly ten times as high in vegans as vegetarians, and more than 50 times higher compared to those who regularly ate animal foods.

Ovo-lacto vegetarians (or people who don't eat animal meat or fish, but do include dairy and eggs in their diet) are at a slightly increased risk of dietary vitamin B12 deficiency, but B12-related medical problems are not common in this group. When medical problems do show up, it is most commonly in people who had eaten a vegetarian diet throughout their entire life, rather than adopting it later on as adults. This pattern makes sense to us, because our bodies are capable of storing large amounts of B12. In fact, it is common for adults to store thousands of times more B12 than their daily requirement. Because significant amounts of B12 are also be recycled around the body, the unusually large body supply of this vitamin can mean years before B12 depletion. So it is logical for an adult vegetarian who ate animal foods and fish growing up to go for long periods before risking B12 depletion, even if B12 intake has been inadequate.

Other Circumstances that Might Contribute to Deficiency

The most common cause of vitamin B12 deficiency symptoms in the U.S. is not a dietary deficiency, but a problem related to malabsorption. This condition is called pernicious anemia, and it is a relatively common condition in older adults. An estimated 10-30% of people over the age of 50 have some amount of malabsorption of this vitamin.

In pernicious anemia, various immune system reactions cause damage to the stomach lining. As a result of this damage, specialized cells in the stomach called parietal cells become unable to produce intrinsic factor (IF). Since IF is needed for B12 absorption, this process results in poor absorption of B12, and the need for much greater amounts of B12 than can be obtained from food. Of course, diagnosis of this condition and the appropriate remedy for pernicious anemia requires the help of a licensed healthcare provider.

Pernicious anemia is not the only absorption-related problem associated with risk of vitamin B12 deficiency. As mentioned at the outset of this article, B12 is an unusual B-complex vitamin in terms of its absorption. Here is a short summary of the complicated nature of B12 absorption:

(1) Stomach acids are needed to release B12 from our food and allow it to bind with a glycoprotein called haptocorrin provided in saliva and in stomach fluids.

(2) When leaving the stomach, protease enzymes provided by the pancreas are needed to separate B12 from haptocorrin and allow it to bind together with intrinsic factor (IF). IF is a specialized glycoprotein release by specialized stomach cells called parietal cells, and its job is to bind together with B12 and facilitate its absorption.

(3) At the very end of the small intestine (called the terminal ileum), intestinal cells have special locations on their outer membranes (consisting of two proteins called cubulin and amionless) and these proteins serve as the location for taking the IF-bound form of B12 out of the intestine and up into the cells.

(4) Once inside the intestinal cells, B12 must be reconfigured and attached to a different protein called transcobalamin for passage through the bloodstream.

These many different digestive tract steps make B12 absorption readily influenced by digestive tract problems. For example, overgrowth of the bacterium *Helicobacter pylori* in the stomach has been associated with increased risk of B12 deficiency. Insufficient secretion of protein-digesting enzymes by the pancreas has also been shown to compromise B12 status. Various other stomach problems have also been associated with increased deficiency risk for this vitamin.

The connection between B12 deficiency risk and digestive problems is believed to be a primary reason for increased risk of B12 deficiency with aging (especially after age 50), since digestive problems also tend to increase during this time period.

While oral contraceptive (OC) use is sometimes mentioned as a risk factor for B12 deficiency, the research seems mixed in this regard. On the one hand, blood levels of B12 have been shown to sometimes drop below the normal range with OC use. But at the same time, these drops in blood levels appear to be temporary and to pose no chronic problems. Interestingly, lower blood levels of B12 in women who use OCs appear to occur independently from dietary intake. In other words, these lower levels of B12 do not appear to change, even if dietary intake of B12 is increased. More research is being done to determine the significant of these findings.

Pregnancy and lactation (breastfeeding) increase the need for B12, and the Dietary Reference Intake (DRI) recommendations for pregnancy and lactation are 2.6 micrograms and 2.8 micrograms, respectively.

Because folate and B12 work so closely together, both folate deficiency and folate excess can increase the need for B12. While folate excess has been controversial in health research primarily in relationship to dietary supplementation of this vitamin in high doses, some scientists believe that folate fortification of food (in the absence of simultaneous B12 fortification) can also create imbalances in the ratio of B12-to-folate. As a remedy, they have recommended simultaneous fortification with both folate and B12 if fortification is determined to be desirable. The bottom line here is to combine a reasonable variety of foods in your meal plan that are nutrient-rich in both B vitamins. Our Healthy Sauteéd Seafood with Asparagus recipe, for example, combines three of our top 10 seafoods rich in B12 (cod, scallops, and shrimp) with our second richest source of folate (asparagus).

Relationship with Other Nutrients

As described earlier in our Health Benefits section, vitamin B12 is involved in the process of energy production. Yet B12 is not the only B-complex vitamin involved in this process, and for this reason, a deficiency of one or more of the other B vitamins may compound energy-production problems that are related to B12 deficiency. In other words, some symptoms of B12 deficiency can be made worse due to other B-vitamin deficiencies.

In particular, the relationship between folic acid, vitamin B6, and vitamin B12 is very close. A deficiency in any one of the three can impair the activity of the others. Most alarmingly, when people use high dose supplements of folic acid, it can be harder to spot vitamin B12 deficiency, leading to more serious symptoms. As described earlier in this article, controversy has also arisen over the role of folate fortification of foods, which has some researchers recommending simultaneous fortification of both folate and B12 whenever fortification with either nutrient is being considered.

Some older sources report that vitamin C can damage or impair absorption of vitamin B12. Further research discounted this hypothesis, so you can probably disregard this if you see it.

Risk of dietary Toxicity

There is no known toxicity risk from dietary vitamin B12. In fact, doctors routinely inject people with deficiency symptoms with very large doses of the vitamin—500 times the daily required intake or more—without evidence of toxicity. You can be confident that your diet does not contain too much vitamin B12.

Disease Checklist

- Pernicious anemia
- Atrophic gastritis
- Neuropathy
- Fatigue
- Depression
- Kidney disease
- Memory loss
- Tinnitus
- Migraine
- Macular degeneration
- Asthma
- Shingles
- Multiple sclerosis

- Alzheimer's disease

Public Health Recommendations

In 1998, the National Academy of Sciences established a set of Dietary Reference Intakes (DRI) that included Recommended Dietary Allowances (RDA) by age for vitamin B12. These are summarized in the chart below. Values for infants under one year old were established in the form of Adequate Intake (AI) levels. The full set of DRI recommendations is listed below:

- 0-6 months: 0.4 mcg
- 6-12 months: 0.5 mcg
- 1-3 years: 0.9 mcg
- 4-8 years: 1.2 mcg
- 9-13 years: 1.8 mcg
- 14+ years: 2.4 mcg
- Pregnant women: 2.6 mcg
- Lactating women: 2.8 mcg

Note that the National Academy of Sciences has advised people over the age of 50 to meet their intake requirements mainly via either fortified foods or using a vitamin B12 supplement. This recommendation is due to the high number of people in this age group with malabsorption of the vitamin.

There is no established Tolerable Upper Intake Level (UL) for vitamin B12. In fact, doctors rather routinely supplement or inject people with pernicious anemia with amounts of vitamin B12 that are several hundred-fold greater than the DRI recommendations. As such, there is no known reason to be concerned about excessive intake of vitamin B12.

The Daily Value (DV) of 6 mcg per day is the value you'll see on food labels. Please note that the more recent DRI values are much lower, and probably a better reflection of your daily needs. We chose the adult DRI (ages 14 and older) of 2.4 micrograms as our daily recommended amount at WHFoods.

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The World's Healthiest Foods

World's Healthiest Foods rich in vitamin B2		
Food	Cals	DRI/DV
Soybeans	298	38%
Spinach	41	32%
Beet Greens	39	32%
Tempeh	222	31%
Yogurt	149	27%
Mushrooms, Crimini	16	27%
Eggs	78	20%
Asparagus	40	19%
Almonds	132	18%
Turkey	167	18%

Basic Description

Vitamin B2, also known as riboflavin, is arguably the only vitamin that gives you a visual cue as to its passage through your body. When there is a lot of vitamin B2 in the diet (or in a supplement), your urine turns bright yellow to show you it is there. In fact, the *—flavin* in riboflavin comes from *flavus,* the Latin word for yellow.

Vitamin B2, like the other B vitamins, is involved in energy metabolism. It has also recently been found to affect the metabolism of iron in important ways.

The World's Healthiest Foods are generally very rich in vitamin B2. In fact, well over half of the foods profiled on our site contain at least 5% of the Dietary Recommended Intake (DRI) for vitamin B2. We rate five of our foods as excellent sources of vitamin B2. Another 12 foods rate as very good sources, while 21 rate as good sources.

Role in Health Support

Promotes Energy Production

Like all the B vitamins, vitamin B2 plays a key role in energy production. Its role here is complicated—it is important both for the energy-producing electron transport chain and the metabolism of fat molecules into chemically useful energy. Additionally, vitamin B2 plays a role in the chemistry of other nutrients involved in energy production, including folate and vitamin B6.

Offers Antioxidant Protection

Vitamin B2 is one of many nutrients required to recycle glutathione, which is one of the most important antioxidants in the human body. (From a chemical standpoint, what B2 does is facilitate the conversion of oxidized glutathione into reduced glutathione.)

We believe that the best protection against free radicals comes from foods that are rich in many different antioxidants. Examples of good vitamin B2 sources that would fit this description include spinach, beet greens, and broccoli, among others.

Promotes Iron Metabolism

Marginal vitamin B2 status has been found to impair the ability to make red blood cells, leading to a condition called anemia. There is some debate about how this occurs, with some scientists believing that vitamin B2 is necessary to mobilize iron from storage to incorporate into cells, and others believing that vitamin B2 deficiency impairs iron absorption.

We believe that both of these could be true and recommend making sure your diet contains rich sources of all the nutrients necessary for blood cell production. Here are a couple of examples of recipes—our Baked Chicken Breast with Honey Mustard Sauce and 10-Minute Rosemary Lamb Chopss—that are rich in both iron and vitamin B2.

Summary of Food Sources

People eating a standard Western diet receive about one-quarter to one-third of their dietary vitamin B2 from milk and other dairy products. If you look at the chart below, you'll see milk and yogurt represented as good sources of vitamin B2. To this day, dairy is probably the best publicized source of this nutrient.

We would encourage you, though, to explore other sources of vitamin B2. For example, crimini mushrooms are an excellent source of vitamin B2, and many leafy green vegetables also end up as good to excellent sources, as well.

In terms of food groups, we see almost all of them containing foods that are contributors to vitamin B2 nutrition. Many non-dairy animal foods—including turkey, sardines, and eggs—end up in the top third of our B2-rich foods. Legumes—and particularly soy foods—are also well represented.

Many types of vegetables are rich in vitamin B2. In addition to leafy greens, which are rich sources of a wide array of nutrients, we see other Brassica vegetables (including broccoli, cauliflower, and Brussels sprouts), peppers, root vegetables, and squash on the list of vitamin B2-rich foods.

You can even get vitamin B2 in some natural sweeteners like maple syrup , which contains about 6% of the RDA in just one teaspoon. Our Ginger Yogurt with Fruit is quite rich in vitamin B2, providing almost 40% of the RDA.

As an example of how easy it can be to build a daily meal plan that meets your vitamin B2 needs, let's do it with three sample meals. For breakfast, we'll choose Huevos Rancheros. For lunch, we'll whip up a Healthy Chef's Salad with Walnuts and French Dressing. For dinner, we'll choose the Healthy Chicken Caeser Salad. This gives you about one and one-half times the RDA for vitamin B2.

Introduction to Nutrient Rating System Chart

In order to better help you identify foods that feature a high concentration of nutrients for the calories they contain, we created a Food Rating System. This system allows us to highlight the foods that are especially rich in particular nutrients. The following chart shows the World's Healthiest Foods that are either an excellent, very good, or good source of vitamin B2. Next to each food name, you'll find the serving size we used to calculate the food's nutrient composition, the calories contained in the serving, the amount of vitamin B2 contained in one serving size of the food, the percent Daily Value (DV%) that this amount represents, the nutrient density that we calculated for this food and nutrient, and the rating we established in our rating system. For most of our nutrient ratings, we adopted the government standards for food labeling that are found in the U.S. Food and Drug Administration's "Reference Values for Nutrition Labeling." Read more background information and details of our rating system.

World's Healthiest Foods ranked as quality sources of vitamin B2						
Food	Serving Size	Cals	Amount (mg)	DRI/DV (%)	Nutrient Density	World's Healthiest Foods Rating
Spinach	1 cup	41.4	0.42	32	14.0	excellent
Beet Greens	1 cup	38.9	0.42	32	15.0	excellent
Mushrooms, Crimini	1 cup	15.8	0.35	27	30.6	excellent
Asparagus	1 cup	39.6	0.25	19	8.7	excellent
Sea Vegetables	1 TBS	10.8	0.14	11	17.9	excellent
Eggs	1 each	77.5	0.26	20	4.6	very good
Cow's milk	4 oz	74.4	0.21	16	3.9	very good
Collard Greens	1 cup	62.7	0.20	15	4.4	very good
Broccoli	1 cup	54.6	0.19	15	4.8	very good
Swiss Chard	1 cup	35.0	0.15	12	5.9	very good
Green Beans	1 cup	43.8	0.12	9	3.8	very good
Mushrooms, Shiitake	0.50 cup	40.6	0.12	9	4.1	very good
Bok Choy	1 cup	20.4	0.11	8	7.5	very good
Turnip Greens	1 cup	28.8	0.10	8	4.8	very good
Kale	1 cup	36.4	0.09	7	3.4	very good
Mustard Greens	1 cup	36.4	0.09	7	3.4	very good

Bell Peppers	1 cup	28.5	0.08	6	3.9	very good
Soybeans	1 cup	297.6	0.49	38	2.3	good
Tempeh	4 oz	222.3	0.40	31	2.5	good
Yogurt	1 cup	149.4	0.35	27	3.2	good
Almonds	0.25 cup	132.2	0.23	18	2.4	good
Turkey	4 oz	166.7	0.23	18	1.9	good
Green Peas	1 cup	115.7	0.21	16	2.5	good
Sweet Potato	1 cup	180.0	0.21	16	1.6	good
Sardines	3.20 oz	188.7	0.21	16	1.5	good
Tuna	4 oz	147.4	0.16	12	1.5	good
Winter Squash	1 cup	75.8	0.14	11	2.6	good
Brussels Sprouts	1 cup	56.2	0.12	9	3.0	good
Grapes	1 cup	104.2	0.11	8	1.5	good
Cabbage	1 cup	43.5	0.09	7	2.9	good
Carrots	1 cup	50.0	0.07	5	1.9	good
Summer Squash	1 cup	36.0	0.07	5	2.7	good
Romaine Lettuce	2 cups	16.0	0.06	5	5.2	good
Cauliflower	1 cup	28.5	0.06	5	2.9	good
Celery	1 cup	16.2	0.06	5	5.1	good
Chili Peppers	2 tsp	15.2	0.05	4	4.5	good
Miso	1 TBS	34.2	0.04	3	1.6	good

World's Healthiest Foods Rating	Rule
excellent	DRI/DV>=75% OR Density>=7.6 AND DRI/DV>=10%
very good	DRI/DV>=50% OR Density>=3.4 AND DRI/DV>=5%
good	DRI/DV>=25% OR Density>=1.5 AND DRI/DV>=2.5%

Impact of Cooking, Storage and Processing

Arguably, the biggest impact on vitamin B2 nutrition in the food processing chain is due to damage from exposure to light. In fact, one of the reasons your milk is likely to come in a paper carton is to reduce the light damage to the vitamin B2 content.

As light damages the vitamin B2, it produces an off-flavor that makes it taste less fresh. It doesn't take much of this effect to become noticeable. A 10% change occurs over a few days in glass exposed to light and studies show that milk drinkers can taste the difference.

Luckily, the dairy industry has developed methodology throughout the packaging and delivery chain to reduce this problem. You can help retain the most vitamin B2 in your dairy products by purchasing it in opaque containers whenever it will be exposed to light. It's also important to note here that the B2 in cheese, yogurt, and other dairy foods is equally susceptible to damage from light, and those foods need opaque storage containers as well.

Vitamin B2 is surprisingly stable to heat and refrigeration. One recent research group found a negligible loss of vitamin B2 over three days of refrigeration.

Historically, vitamin B2 was believed to be the heat stable fraction of vitamin B. That said, there is some loss of vitamin B2 with prolonged cooking techniques. For example, in one research study, milk boiled for 15 minutes loses 27% of its initial vitamin B2 content.

Like most of the other B vitamins, processing of grains from whole to refined robs them of much of the vitamin B2 content. For example, 60% extraction flour, (the kind most commonly used in ordinary white bread, where 40% of the whole grain is lost during processing), contains only one-fifth of the vitamin B2 content of whole unprocessed wheat. The majority of states in the U.S. require "enrichment" of these highly processed flours with B2 (as well as B1, B3, folic acid, and iron). And

manufacturers in all states generally comply with the Food and Drug Administration's voluntary guideline for enrichment of processed flour, which has been around since the 1940's.

In short, then, the best way to ensure good vitamin B2 content of foods is to eat them fresh, keep them (dairy in particular) from prolonged exposure to light, and keep cooking times brief. Following the meal plans on our site you'll be encouraged to do all three.

Risk of Dietary Deficiency

The risk of deficiency of vitamin B2 in the United States is not very high. It appears that only about 2% of American adults fail to reach the Dietary Reference Intake (DRI) for vitamin B2.

There is an emerging concern about vitamin B2 intake in adolescents, especially adolescent girls. This is the combined result of a reduced intake of dairy products and a well-known aversion to fruits and vegetables in this age group.

We believe that the amount of fresh and varied foods in the World's Healthiest Foods recipe library should ensure that you do not become deficient in vitamin B2.

It is really not difficult to build a diet rich in vitamin B2 using the World's Healthiest Foods. A serving of a soy food—for example, whole soybeans or tempeh—gets you a quarter of the way there. Adding another high-vitamin B2 food such as spinach or yogurt will get you over half a day's supply. From here, a smattering from any of a number of good vitamin B2 sources—and there are many to choose from—should get you to your target.

Other Circumstances that Might Contribute to Deficiency

As noted above, the risk of vitamin B2 deficiency is not very high and usually requires some special circumstances. Aggressive medication protocols for cancer and AIDS have been reported to cause vitamin B2 deficiency. Vitamin B2 deficiency has also been noted in some indigenous populations that eat diets devoid of plant foods.

Relationship with Other Nutrients

Vitamin B2 deficiency can impair blood cell production. Although there is some debate about how this happens, it appears that vitamin B2 is necessary to incorporate dietary iron into the forming red blood cell. It has also been hypothesized that deficient vitamin B2 stores impair the absorption of dietary iron.

However this interaction occurs, two separate research groups have shown improvements in blood cell counts through restoring vitamin B2 to the diet in people who had low levels of the vitamin.

As noted above, the stability of vitamin B2 in foods is questionable during storage, particularly if the food is exposed to light. Researchers have recently learned that having other antioxidants in the food, particularly vitamin C, may help to spare the vitamin B2 content.

Vitamin B2 is necessary to convert vitamin B6 to its active form. Hence, deficiency of vitamin B2 could potentially reduce your ability to use vitamin B6, even when there is plenty in your diet.

Risk of dietary Toxicity

There are to date no credible reports of toxicity from vitamin B2 that we were able to find. The National Academy of Sciences, similarly unable to demonstrate any health risk, chose not to establish a Tolerable Upper Intake Limit (UL) for vitamin B2 intake.

Since research trials have used doses of supplemental vitamin B2 more than 20 times the Dietary Reference Intake (DRI) without any evidence for adverse effect, we believe it is highly unlikely that you could eat too much vitamin B2 under any circumstance.

One warning, though—vitamin B2 can tend to make the urine appear very yellow. Diets rich in vitamin B2 may induce this effect. It is not considered harmful, but it may appear unusual at first.

Disease Checklist

- Iron deficiency anemia
- Migraine headache
- Congestive heart failure
- High homocysteine
- Cataract
- Parkinson's disease
- Hypertension

Public Health Recommendations

In 1998, the Food and Nutrition Board of the National Academy of Sciences (NAS) established a set of Dietary Reference Intakes (DRIs) for vitamin B2 that included Recommended Dietary Intakes (RDAs) by age and gender. Note that the standards for infants under one year of age are Adequate Intake (AI) standards. These are summarized below.

- 0-6 months: 0.3 mg
- 6-12 months: 0.4 mg
- 1-3 years: 0.5 mg
- 4-8 years: 0.6 mg
- 9-13 years: 0.9 mg
- 14-18 years, female: 1.0 mg
- 14-18 years, male: 1.3 mg
- 19+ years, female: 1.1 mg
- 19+ years, male: 1.3 mg
- Pregnant women: 1.4 mg
- Lactating women: 1.6 mg

Given the lack of demonstrated toxicity of vitamin B2, the NAS chose not to establish a Tolerable Upper Limit (UL) for vitamin B2 intake.

The Daily Value (DV) for vitamin B2 is 1.7 mg per 2000 calories. This is the value that food labels use as a reference point.

As our WHFoods recommendation for daily intake of vitamin B2, we chose the Dietary Reference Intake (DRI) level for men 14 and older of 1.3 milligrams. (This level is about 20% higher than the DRI for women 19 and older of 1.1 milligrams, and we chose it to make sure that both men and women would be covered by the guideline.)

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The World's Healthiest Foods

World's Healthiest Foods rich in vitamin B3		
Food	Cals	DRI/DV
Tuna	147	156%
Chicken	187	97%
Turkey	167	83%
Salmon	158	56%
Lamb	310	50%
Beef	175	48%
Sardines	189	30%
Peanuts	207	28%
Shrimp	135	19%
Brown Rice	216	19%

Basic Description

Niacin is a blanket term for a family of compounds with vitamin B3 activity. The terms "niacin" and "vitamin B3" can be used interchangeably, and whenever you find either term on our website, we are referring to the same group of compounds. Basic types of vitamin B3 include nicotinamide, nicotinic acid, and several active enzymatic forms, each of which can be obtained from food. In research studies, nicotinamide is used as a standard of measurement for calculating the vitamin B3-activity associated with each forms of niacin, prompting researchers to use the term "NE" when referring to B3 measurements. "NE" in this situation stands for "niacin equivalents." Many public health organizations make B3 recommendations in terms of "milligrams of NEs" per day. When you see this type of reference, it simply means that all forms of B3 found in whole foods count as good ways to meet your daily B3 needs.

You may have heard the term "pellagra," and if you associate this term with diet- and nutrition-related problems, you are correct. Pellagra is the name of a disease that is characterized by nutrient defiency, and primarily deficiency of vitamin B3. It took a long time for healthcare community—both in the U.S. and worldwide—to recognize that dietary changes as simple as adding animal foods and legumes to a meal plan could help prevent pellagra. Between 1900 and 1940, more than 100,000 people in the United States—mostly those who were poor, African-American, female, and from southern states—died from an epidemic of pellagra stemming from poverty and malnourishment. This epidemic was wrongly ascribed to several possible causes, including infection. It was also a primary reason for steps taken by the U.S. Department of Agriculture (USDA) in 1938 to authorize the enrichment of wheat flour with niacin. ("Enrichment" refers to the addition of nutrient supplements during food processing.)

Consumption of enriched wheat flour, however, is by no means required for adequate niacin intake. Your diet is likely to have the recommended daily amount of B3 if you have multiple daily servings of whole, natural foods across a wide variety of food groups.

The World's Healthiest Foods list contains four excellent sources of niacin—tuna, chicken, turkey, and crimini mushrooms. We also list six very good sources and 34 good sources. A number of our recipes are very niacin rich, including 13 that contain more than the Dietary Reference Intake (DRI) requirement.

Role in Health Support

Energy Production

Like the other B complex vitamins, niacin is important in energy production. Two unique forms of vitamin B3 (called nicotinamide adenine dinucleotide, or NAD, and nicotinamide adenine dinucleotide phosphate, or NADP) are essential for conversion of dietary proteins, fats, and carbohydrates into usable energy. Niacin is also used to synthesize starch that can be stored in muscles and liver for eventual use as an energy source.

Antioxidant Protection

The same niacin-containing enzymes that are involved in energy metabolism, NAD and NADP, work by quenching free radicals. This process is not only important in energy production, but in protecting your body against excessive tissue damage. While most lay person nutrition sources omit niacin from the list of dietary antioxidants, researchers are aware of this connection, and have studied it extensively, particularly in people with diabetes.

Summary of Food Sources

Other than crimini mushrooms and asparagus, all of the excellent and some of the very good sources of B3 in our rating system are animal-derived foods. Six of these contain 50% or more of the DRI recommendation for the nutrient.

The good sources of niacin come from many different food groups. We see legumes (particularly peanuts and green peas) represented. A number of vegetables, particularly root vegetables and leafy greens, also show up as good niacin sources. We also find fruits (cantaloupe), nuts/seeds (sunflower seeds), and grains (brown rice, barley).

It is pretty easy to build a menu with a full day's supply of B3 using a small number of the World's Healthiest Foods. For example, you could include a recipe that includes both Green Peas and Crimini Mushrooms at lunch. At dinner, you could enjoy a recipe that features fish such as our 15-Minute Salmon with Mustard Dill Sauce. And with those two dishes, you've well exceeded the DRI for niacin.

Or if you'd like a more direct way to exceed your daily B3 requirement, try our Warm Spinach Salad with Tuna recipe and get more than twice the DRI from this single meal.

Introduction to Nutrient Rating System Chart

In order to better help you identify foods that feature a high concentration of nutrients for the calories they contain, we created a Food Rating System. This system allows us to highlight the foods that are especially rich in particular nutrients. The following chart shows the World's Healthiest Foods that are either an excellent, very good, or good source of vitamin B3. Next to each food name, you'll find the serving size we used to calculate the food's nutrient composition, the calories contained in the serving, the amount of vitamin B3 contained in one serving size of the food, the percent Daily Value (DV%) that this amount represents, the nutrient density that we calculated for this food and nutrient, and the rating we established in our rating system. For most of our nutrient ratings, we adopted the government standards for food labeling that are found in the U.S. Food and Drug Administration's "Reference Values for Nutrition Labeling." Read more background information and details of our rating system.

World's Healthiest Foods ranked as quality sources of vitamin B3						
Food	Serving Size	Cals	Amount (mg)	DRI/DV (%)	Nutrient Density	World's Healthiest Foods Rating
Tuna	4 oz	147.4	25.03	156	19.1	excellent
Chicken	4 oz	187.1	15.55	97	9.3	excellent
Turkey	4 oz	166.7	13.32	83	9.0	excellent
Mushrooms, Crimini	1 cup	15.8	2.74	17	19.5	excellent
Salmon	4 oz	157.6	9.02	56	6.4	very good
Lamb	4 oz	310.4	8.05	50	2.9	very good
Beef	4 oz	175.0	7.60	48	4.9	very good
Asparagus	1 cup	39.6	1.95	12	5.5	very good
Tomatoes	1 cup	32.4	1.07	7	3.7	very good
Bell Peppers	1 cup	28.5	0.90	6	3.6	very good
Sardines	3.20 oz	188.7	4.76	30	2.8	good
Peanuts	0.25 cup	206.9	4.40	28	2.4	good
Shrimp	4 oz	134.9	3.04	19	2.5	good
Brown Rice	1 cup	216.4	2.98	19	1.5	good
Sweet Potato	1 cup	180.0	2.97	19	1.9	good
Sunflower Seeds	0.25 cup	204.4	2.92	18	1.6	good
Barley	0.33 cup	217.1	2.82	18	1.5	good
Green Peas	1 cup	115.7	2.78	17	2.7	good

Potatoes	1 cup	160.9	2.44	15	1.7	good
Cod	4 oz	96.4	1.52	10	1.8	good
Corn	1 each	73.9	1.30	8	2.0	good
Carrots	1 cup	50.0	1.20	8	2.7	good
Cantaloupe	1 cup	54.4	1.17	7	2.4	good
Mushrooms, Shiitake	0.50 cup	40.6	1.09	7	3.0	good
Collard Greens	1 cup	62.7	1.09	7	2.0	good
Winter Squash	1 cup	75.8	1.01	6	1.5	good
Brussels Sprouts	1 cup	56.2	0.95	6	1.9	good
Summer Squash	1 cup	36.0	0.92	6	2.9	good
Spinach	1 cup	41.4	0.88	6	2.4	good
Broccoli	1 cup	54.6	0.86	5	1.8	good
Green Beans	1 cup	43.8	0.77	5	2.0	good
Bok Choy	1 cup	20.4	0.73	5	4.0	good
Beet Greens	1 cup	38.9	0.72	5	2.1	good
Soy Sauce	1 TBS	10.8	0.71	4	7.4	good
Kale	1 cup	36.4	0.65	4	2.0	good
Chili Peppers	2 tsp	15.2	0.63	4	4.7	good
Swiss Chard	1 cup	35.0	0.63	4	2.0	good
Mustard Greens	1 cup	36.4	0.61	4	1.9	good
Eggplant	1 cup	34.6	0.59	4	1.9	good
Turnip Greens	1 cup	28.8	0.59	4	2.3	good
Cabbage	1 cup	43.5	0.57	4	1.5	good
Fennel	1 cup	27.0	0.56	4	2.3	good
Cauliflower	1 cup	28.5	0.51	3	2.0	good
Sea Vegetables	1 TBS	10.8	0.46	3	4.8	good
Parsley	0.50 cup	10.9	0.40	3	4.1	good

World's Healthiest Foods Rating	Rule
excellent	DRI/DV>=75% OR Density>=7.6 AND DRI/DV>=10%
very good	DRI/DV>=50% OR Density>=3.4 AND DRI/DV>=5%
good	DRI/DV>=25% OR Density>=1.5 AND DRI/DV>=2.5%

Impact of Cooking, Storage and Processing

In terms of storage, the B3 in whole natural foods tends to be relatively stable. If you store foods using the approaches we recommend in our website food profiles (in the sections entitled, "How to Select and Store," the B3 in your foods should still be there when you are ready to consume them.

However, cooking is another matter. As a water-soluble vitamin, B3 is susceptible to leeching out of your food and into cooking water. We've seen a study of the boiling of meat where about twice as much B3 was lost from boiling versus pan-frying. While we are not recommending that you pan-fry meats, we view this research as consistent with the principle that a water-soluble vitamin like B3 can leech into cooking water. Our Healthy Steaming method allows you to avoid submersion of foods in water; our Healthy Sauté methods allows you to use a relatively small amount of liquid, and our Quick Boil method helps you keep the time of submersion in water to a minimum. All of these methods are intended to help you reduce nutrient loss during cooking, especially loss of water-soluble nutrients like B3.

You might be interested to know that in many foods traditions—including Native American traditions—communities eating local, seasonal, whole, natural foods developed ways of improving their B3 intake. One way involved the preparation of corn. In many tribal traditions across North America where corn (traditionally called maize) played an important role in the daily meal plan, hominy (made from corn kernels) and other corn dishes were prepared by soaking and/or cooking corn mixtures with a compound made from wood ash. In this process, ash from wood fires was boiled down to produce a white residue called

"potash"—literally "pot ash." From a chemical standpoint, potash provided a variety of potassium-containing salts and especially potassium carbonate. Like lye (sodium hydroxide) and lime (calcium hydroxide), the boiling of corn mixtures in potash was able to create a very alkaline fluid that helped change the chemical structure of the corn. (Even today, you will find lime—calcium hydroxide—to be a very common ingredient in many store-bought tortillas, tamales, and tortilla chips. Within the context of today's food industry, the processing of corn in a "limewater" solution allows formation of a dough from the corn.) Within traditional Native American cuisines, however, one of the most important changes brought about by the potash soaking and boiling of corn was to make its B3 much more available for digestion when the corn was eaten. This cooking method helped many groups of Native Americans who were dependent on corn for their nourishment to greatly lower their risk of B3 deficiency and pellagra.

Risk of Dietary Deficiency

Many circumstances have combined to dramatically reduce the risk of B3 deficiency in the average U.S. diet. These circumstances include widespread consumption of animal foods—including chicken and turkey—as well as addition of B3 to grain products (like wheat flour or corn meal). The average U.S. adult (age 20 and over) consumes about 26 milligrams of B3 per day, or about 160% of our WHFoods recommended intake amount of 16 milligrams.

Even though animal foods and fish are our richest sources of B3 (with single servings often providing 25% or more of the needed daily amount), it is not difficult for a vegetarian diet to provide ample amounts of B3. Mushrooms, legumes, seeds, and fresh vegetables are often rich in B3. As an example, one serving of crimini mushrooms, one serving of peanuts, one serving sunflower seeds, one serving of sweet potato, and one serving of brown rice add up to about 825 calories and 100% of your daily B3 requirement.

Other Circumstances that Might Contribute to Deficiency

In industrialized countries, world, most instances of vitamin B3 deficiency appear to be related to medical conditions. By far the most likely reason to see niacin deficiency is alcoholism, a condition that can compromise not only B3 status, but the status of many other nutrients as well. .

Relationship with Other Nutrients

The traditional definition of a vitamin is a compound necessary for normal growth and nutrition that is needed from food since the human body cannot produce it. While we don't find any basic fault with this definition, we also know that in a technical sense, it is not always correct. In the case of some vitamins, there are ways for the body to make the vitamin even if the vitamin is not preformed and already existing in food. Interestingly, niacin is one of the vitamins that "breaks the rules" in terms of the traditional definition.

Niacin can be synthesized in the body from the amino acid tryptophan. So in principle, it might be possible for a person to get all of the niacin they need from the tryptophan found in protein-rich foods, even if those foods contained no niacin. From a practical standpoint, however, many protein-rich foods (like animal foods) are also rich in niacin, so that there would be no practical need to take the tryptophan in these foods and convert it into niacin. (The rate of conversion from tryptophan to niacin in the human body is estimated to be somewhere in the range of 60:1, meaning that 60 milligrams of tryptophan would be required to create one milligram of niacin.) There is no question that the human body—under some circumstances, which are still being actively investigated—takes tryptophan and converts it into niacin. But exactly how important this process is to our B3 status is not clear. Among the complicated issues in this area of tryptophan-to-niacin conversion is the role of other nutrients required for conversion. Vitamin B6, for example, is clearly needed for conversion of tryptophan into niacin, and researchers aren't clear how relative deficiencies in B6 might affect the conversion process. We look forward to future research in this area that will help us better understand this aspect of B3.

Risk of dietary Toxicity

There is no known risk of dietary toxicity from naturally occurring niacin in foods. Even in the case of our most niacin-rich animal meats and fish, we are not aware of any research showing toxicity risk for B3. In keeping with this clean research bill of health, the National Academy of Sciences (NAS) has not set any Tolerable Upper Intake Level (UL) for B3 when obtained from whole, natural foods. However, the NAS has set ULs for B3 in supplement form and in processed foods that have been fortified with B3. While we do not believe that fortification with B3 generally serve to increase risk of excess B3 intake, we would point out that some ready-to-eat (RTE), heavily fortified breakfast cereals can sometimes contain relatively high amounts of B3 (in some cases, up to 20 milligrams per 1-cup serving, although 5-10 milligrams is a more common range in

fortified RTE cereals). In the case of a young child under the age of 8 years, this amount of B3 from a fortified food could actually exceed the UL as established by the NAS. We would like to be very clear that we have seen no evidence to show that intake of B3 from fortified foods has resulted in any actual health problems. However, simply looking from the perspective of the ULs and B3 content from specific fortified products, we can see how the ULs could potentially be exceeded under certain circumstances, especially for younger age groups. Below is a complete list of ULs for vitamin B3 intake from supplements and fortified foods:

Upper Limits for Vitamin B3 From Supplements and Fortified Foods

- 1-3 years: 10 milligrams
- 4-8 years: 15 milligrams
- 9-13 years: 20 milligrams
- 14-18 years: 30 milligrams
- 19 years and olders: 35 milligrams
- Pregnant or lactating women, 18 years and younger: 30 milligrams
- Pregnant or lactating women, 19 years and older: 35 milligrams

Just to repeat: the above limits do not apply to vitamin B3 when it is consumed from whole, natural foods. When consuming vitamin B3 from whole, natural foods, this general adult limit of 35 milligrams can be exceeded and is not considered to be a toxicity health risk.

Disease Checklist

- Pellagra
- High cholesterol
- Acne vulgaris
- Osteoarthritis
- Reynaud's disease
- Schizophrenia
- Type 1 diabetes

Public Health Recommendations

In 1998, the National Academy of Sciences published Dietary Reference Intakes (DRIs) for vitamin B3. These DRIs included Adequate Intake (AI) levels for children under one year of age and Recommended Dietary Allowances (RDAs) for all other individuals. We have used the DRI for adult males as the standard for the nutrient charts on this page.These DRIs for vitamin B3 are listed below:.

- 0-6 months: 2 mg
- 6-12 months: 4 mg
- 1-3 years: 6 mg
- 4-8 years: 8 mg
- 9-13 years: 12 mg
- 14+ years, female: 14 mg
- 14 years, male: 16 mg
- Pregnant women: 18 mg
- Lactating women: 16 mg

The Daily Value (DV) for niacin intake that you will see referenced on food labels is 20 mg per 2000 calories.

As our recommended daily intake level for vitamin B3 at WHFoods, we chose the DRI for males ages 14 and older of 16 milligrams. All of our food rating charts use this level for calculating B3-richness in foods.

The DRIs also established Tolerable Upper Intake Levels (ULs) for vitamin B3. However, as reviewed earlier in the Risk of Dietary Toxicity section of this profile, the ULs for vitamin B3 do not apply to intake of this vitamin from whole, natural foods, but only to intake of B3 from dietary supplements and processed foods that have been fortified with additional B3 during processing. The ULs for intake of B3 from supplements and fortified foods (but not applicable to whole, natural foods) are as follows.

- 1-3 years: 10 milligrams
- 4-8 years: 15 milligrams
- 9-13 years: 20 milligrams
- 14-18 years: 30 milligrams
- 19 years and olders: 35 milligrams
- Pregnant or lactating women, 18 years and younger: 30 milligrams
- Pregnant or lactating women, 19 years and older: 35 milligrams

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The World's Healthiest Foods

World's Healthiest Foods rich in vitamin B6		
Food	Cals	DRI/DV
Tuna	147	69%
Turkey	167	54%
Beef	175	44%
Chicken	187	40%
Salmon	158	38%
Sweet Potato	180	34%
Potatoes	161	32%
Sunflower Seeds	204	28%
Spinach	41	26%
Banana	105	25%

Basic Description

Vitamin B6 is a water-soluble vitamin that is found in a variety of forms in the foods we eat as well as in our bodies. These forms include pyridoxal 5'-phosphate (PLP), which appears to be the most active form as a human vitamin. Other forms include pyridoxal (PL), pyridoxamine (PM), pyridoxine (PN), pyridoxamine 5'-phosphate (PMP) and pyridoxine-5'-phosphate (PNP). Nearly half of all WHFoods provide you with measurable amounts of vitamin B6. In addition, you can find nearly 30 excellent or very good sources of this nutrient among our core 100 WHFoods.

There has been substantial debate about blood levels of vitamin B6 and their relationship both to dietary intake and overall health. This debate has centered around the fact that a person can consume the recommended dietary amount of vitamin B6 (our WHFoods recommended level is 1.7 milligrams) and yet have a blood level of vitamin B6 (in the form of plasma PLP) that may not be optimal for metabolism. While we continue to recommend the highest adult Dietary Reference Intake (DRI) level for B6 as established by the National Academy of Sciences, we recognize that this amount might eventually be revised upward based on future research in this area. We would also note that the Tolerable Upper Limit (UL) for vitamin B6 is set at a relatively high level of 100 milligrams for adults, allowing plenty of room for B6 intake substantially above the DRI level.

Role in Health Support

Production of Red Blood Cells

Hemoglobin is complicated protein present in red blood cells, and one of its primary roles is to help carry oxygen around the body. Heme is a key section of the hemoglobin molecule and the initial production of heme in bodies requires the presence of vitamin B6. (Although heme production can occur in multiple places throughout the body, the primary places involve the liver and bone marrow.) The importance of vitamin B6 in red blood cell production is underscored by relatively rare types of anemia called sideroblastic anemias.

Metabolism of Carbohydrates

Vitamin B6 is involved at several steps in the metabolism of carbohydrates. In particular, the enzyme that pulls carbohydrates out of storage in the cell (in the form of a molecule called glycogen) requires vitamin B6 for its activity.

While nobody would do an experiment like this in humans, researchers have been able to induce problems in carbohydrate metabolism by feeding rats diets deficient in vitamin B6. Since breakdown of carbohydrates is an ongoing process that occurs in our bodies throughout the day to help us sustain our physical energy level, daily consumption of whole foods rich in B6 also makes good sense for maintaining ongoing energy levels.

Brain and Nervous System Health

Vitamin B6 is one of several B vitamins required for proper production of messaging molecules in our nervous system and brain (called neurotransmitters). Three key neurotransmitters—namely GABA, dopamine, and serotonin—all require vitamin B6 for synthesis.

Just as an example of how important this nutrient can be to proper brain and nervous system, function, there is a condition called pyridoxine-dependent epilepsy where a genetic mutation interferes with normal vitamin B6 function. In people who have this mutation, the brain does not develop properly and epileptic seizures are experienced beginning in infancy. Luckily, this condition is rare.

However, we may be at risk of other more common problems that can be brain and nervous-system related if our B6 intake is poor. Depression is a good example in this area. Researchers in Japan have found that the risk of depressed mood is higher in people with lower levels of vitamin B6 in their diet (in comparision with the general population). Another research group concluded that this link between risk of depression and B6 intake becomes even stronger when dietary folic acid—a nutrient that works very closely with vitamin B6 in brain and nervous system chemistry—is deficient as well. Recent research has also begun to indicate a link between B6 deficiency and risk of development for attention deficit disorder (ADHD). So once again, we are looking at the possible widespread importance of B6 for brain and nervous system support.

Liver Detoxification

Generally speaking, we remove unwanted chemicals from our blood in the liver and kidney, and this process involves two steps. The first of these two steps is to make the chemicals more water soluble to allow for the second step of binding and removal. The number of nutrients required for this first step is long, but vitamin B6 is clearly one of the most important. It is so important that researchers can induce liver dysfunction in animals by feeding them a pyridoxine-depleted diet.

Other Health Support Roles

Preliminary research on inflammation-related chronic diseases has shown likely connections between the risk of these diseases and B6 deficiency. Interestingly, in addition to increased risk of these conditions in association with B6 deficiency, the presence of chronic inflammatory conditions also appears to be associated with depletion of vitamin B6.

In animal studies, B6 has been shown to play a role in the development of healthy immune system function. This potential health benefit from B6 appears to be associated with its role in metabolism of the amino acid tryptophan.

As mentioned earlier, B6 plays a well-researched role in the synthesis and metabolism of certain nervous system messaging molecules. While we emphasized the nervous system aspects of this health support role earlier in this section, we would also like to point out that the messaging molecules pathways described earlier involve specific amino acids (building blocks of protein), making B6 a potentially important vitamin for support of general amino acid and protein-related metabolism. Interestingly, many of our WHFoods that rank as excellent or very good sources of protein also rank as excellent or very good sources of B6. This overlap may not be a coincidence, given the role played by B6 in protein and amino acid metabolism. It is also worth mentioning that diets especially high in protein may increase risk of B6 depletion, even though many protein-rich foods are also rich in B6. The reason for this risk involves differing nutrient concentrations in which the concentration of protein in a particular food might be significantly greater than the concentration of B6. While this difference might not be important at ordinary protein intakes, unusually high intakes (for example, intakes well over 100 grams) might make the difference more of an issue.

Summary of Food Sources

We see an unusually wide variety of foods listed as good to excellent sources of vitamin B6. As mentioned earlier, nearly half of our WHFoods fall into this category. Plant and animal foods are both well represented. In our top sources by nutrient richness, we see leafy and root vegetables, along with fruit, fish, and fowl. This variety will allow for many choices for a B6-rich diet plan.

With the exception of tuna, all of our excellent sources of vitamin B6 are vegetables. As with so many other nutrients, our discussion of B6-rich foods starts here. We encourage having at least a serving of greens most days, if not every day, along with several other minimally cooked fresh vegetables. And we encourage you not to skimp on the amount, but to consider having 1-1/2 cups in a serving.

In the non-plant category, we have one excellent source of B6 in tuna, and several very good source in beef, chicken, and salmon. And if we continue on into the good category, we pick up shrimp and cod as well.

Some, but not all, fruits are strong sources of vitamin B6. Bananas, pineapples, and avocados are all good to very good sources of this nutrient.

A number of legumes contain between 10-30% of the DRI for vitamin B6 per serving and can be good contributors toward your intake goal. Similarly, a number of the whole grains contain 10-20% of the DRI and can help to build up your daily vitamin B6 nutrition.

This wide variety of food choices for obtaining B6 means that a meal plan focused on our WHFoods has a great chance of providing our WHFoods recommended level of 1.7 milligrams per day. In fact, an average day in our Healthy Way of Eating sample weekly menu contains just shy of 140% of the DRI for vitamin B6.

Let's look in a little more depth at how our Healthy Way of Eating menu breaks down. On Wednesday, we have a number of B6-rich foods. Avocado and chicken each contribute more than 20% of the DRI per serving. We then have a few other foods around 10% of the DRI, including navy and black beans, onion, and tomatoes. From there, we are pretty close to our daily goal, and the contributions from the rest of the foods push us well above the DRI. As mentioned earlier, exceeding the DRI might turn out to be a helpful step if future research on blood levels of PLP confirms a clear advantage to higher levels. And 140% of the DRI level is still far below the Tolerable Upper Limit (UL) of 100 milligrams.

Introduction to Nutrient Rating System Chart

In order to better help you identify foods that feature a high concentration of nutrients for the calories they contain, we created a Food Rating System. This system allows us to highlight the foods that are especially rich in particular nutrients. The following chart shows the World's Healthiest Foods that are either an excellent, very good, or good source of vitamin B6. Next to each food name, you'll find the serving size we used to calculate the food's nutrient composition, the calories contained in the serving, the amount of vitamin B6 contained in one serving size of the food, the percent Daily Value (DV%) that this amount represents, the nutrient density that we calculated for this food and nutrient, and the rating we established in our rating system. For most of our nutrient ratings, we adopted the government standards for food labeling that are found in the U.S. Food and Drug Administration's "Reference Values for Nutrition Labeling." Read more background information and details of our rating system.

World's Healthiest Foods ranked as quality sources of vitamin B6						
Food	Serving Size	Cals	Amount (mg)	DRI/DV (%)	Nutrient Density	World's Healthiest Foods Rating
Tuna	4 oz	147.4	1.18	69	8.5	excellent
Spinach	1 cup	41.4	0.44	26	11.3	excellent
Cabbage	1 cup	43.5	0.34	20	8.3	excellent
Bok Choy	1 cup	20.4	0.28	16	14.5	excellent
Bell Peppers	1 cup	28.5	0.27	16	10.0	excellent
Turnip Greens	1 cup	28.8	0.26	15	9.6	excellent
Garlic	6 cloves	26.8	0.22	13	8.7	excellent
Cauliflower	1 cup	28.5	0.21	12	7.8	excellent
Turkey	4 oz	166.7	0.92	54	5.8	very good
Beef	4 oz	175.0	0.74	44	4.5	very good
Chicken	4 oz	187.1	0.68	40	3.8	very good
Salmon	4 oz	157.6	0.64	38	4.3	very good
Sweet Potato	1 cup	180.0	0.57	34	3.4	very good
Potatoes	1 cup	160.9	0.54	32	3.6	very good
Banana	1 medium	105.0	0.43	25	4.3	very good
Winter Squash	1 cup	75.8	0.33	19	4.6	very good
Broccoli	1 cup	54.6	0.31	18	6.0	very good
Brussels Sprouts	1 cup	56.2	0.28	16	5.3	very good
Collard Greens	1 cup	62.7	0.24	14	4.1	very good
Beet Greens	1 cup	38.9	0.19	11	5.2	very good
Kale	1 cup	36.4	0.18	11	5.2	very good
Carrots	1 cup	50.0	0.17	10	3.6	very good

Swiss Chard	1 cup	35.0	0.15	9	4.5	very good
Asparagus	1 cup	39.6	0.14	8	3.7	very good
Mustard Greens	1 cup	36.4	0.14	8	4.1	very good
Tomatoes	1 cup	32.4	0.14	8	4.6	very good
Leeks	1 cup	32.2	0.12	7	3.9	very good
Summer Squash	1 cup	36.0	0.12	7	3.5	very good
Chili Peppers	2 tsp	15.2	0.11	6	7.6	very good
Sunflower Seeds	0.25 cup	204.4	0.47	28	2.4	good
Pinto Beans	1 cup	244.5	0.39	23	1.7	good
Avocado	1 cup	240.0	0.39	23	1.7	good
Lentils	1 cup	229.7	0.35	21	1.6	good
Green Peas	1 cup	115.7	0.30	18	2.7	good
Lima Beans	1 cup	216.2	0.30	18	1.5	good
Onions	1 cup	92.4	0.27	16	3.1	good
Shrimp	4 oz	134.9	0.27	16	2.1	good
Pineapple	1 cup	82.5	0.18	11	2.3	good
Cod	4 oz	96.4	0.15	9	1.6	good
Mushrooms, Shiitake	0.50 cup	40.6	0.12	7	3.1	good
Cantaloupe	1 cup	54.4	0.12	7	2.3	good
Corn	1 each	73.9	0.11	6	1.6	good
Beets	1 cup	74.8	0.11	6	1.6	good
Eggplant	1 cup	34.6	0.09	5	2.8	good
Turmeric	2 tsp	15.6	0.08	5	5.4	good
Mushrooms, Crimini	1 cup	15.8	0.08	5	5.3	good
Green Beans	1 cup	43.8	0.07	4	1.7	good
Celery	1 cup	16.2	0.07	4	4.6	good
Strawberries	1 cup	46.1	0.07	4	1.6	good
Watermelon	1 cup	45.6	0.07	4	1.6	good
Romaine Lettuce	2 cups	16.0	0.07	4	4.6	good
Figs	1 medium	37.0	0.06	4	1.7	good
Sea Vegetables	1 TBS	10.8	0.05	3	4.9	good

World's Healthiest Foods Rating	Rule
excellent	DRI/DV>=75% OR Density>=7.6 AND DRI/DV>=10%
very good	DRI/DV>=50% OR Density>=3.4 AND DRI/DV>=5%
good	DRI/DV>=25% OR Density>=1.5 AND DRI/DV>=2.5%

Impact of Cooking, Storage and Processing

The pyridoxine form of vitamin B6 found in foods tend to be fairly stable to storage. It takes approximately one year for about 25% of the B6 in various foods to be lost, and even though this amount is relatively high, there are no foods that we recommend storing for this prolonged period of time. In fact, most of the WHFoods that rank as excellent or very good sources of B6 are foods that we recommend be consumed as fresh as possible.

Prolonged exposure to heat can degrade vitamin B6 in most foods. Perhaps as a result of the difference in structural forms, we see more degradation of this vitamin in animal meats than in vegetables.

Both steaming and boiling result in relatively low amounts of B6 loss. We've see research on Brussels sprouts, for example, showing 10-20% loss of B6 based on these two cooking methods. (As in most research on steaming and boiling, boiling in this study resulted in greater B6 loss than steaming, presumably because of submersion in water allowing more surface-to-water contact with the Brussels sprouts.)

Perhaps counterintuitively, lower pH tends to stabilize the vitamin under heat. So adding a little vinegar or tomato into a sauce, for example, may help keep the vitamin B6 more intact.

Risk of Dietary Deficiency

Based on National Health and Nutrition Examination Survey (NHANES) data from 2009-2010, average intake of vitamin B6 for men and women 20 years and older —as well as all U.S. citizens ages 2 and older—was above our WHFoods recommended daily intake level for B6 of 1.7 milligrams.

As mentioned earlier in this article, however, there has been significant debate in the clinical research over the relationship between blood levels of vitamin B6 and overall health, and it is possible that consumption of the DRI level for B6 may not support optimal blood levels of the PLP form of this vitamin. Exactly how this specific area of clinical research relates to overall B6 deficiency risk is an area of research that will be important to follow in future studies.

Other Circumstances that Might Contribute to Deficiency

Women who take oral contraceptive pills (OCP) have an increased risk of vitamin B6 deficiency. According to one research group, 40% of OCP users have biochemical evidence for deficiency, a number much greater than would be predicted based on diet alone.

OCP are not unique in their ability to lead to loss of vitamin B6. A number of other medications have been reported to have this effect, including steroids, antibiotics, and drugs used to treat Parkinson's disease.

Even at a consistent dietary intake, people over the age of 65 years show lower blood levels of vitamin B6. There are several proposed explanations for this phenomenon, including decreased absorption, more difficulty activating the vitamin to its most active form, and increased breakdown. Regardless of the cause, older people may need to pay special attention to dietary vitamin B6 intake. In fact, the highest DRI set for B6 by the National Academy of Sciences (other than the DRIs related to pregnancy and lactation) is the DRI for older men of 1.7 milligrams.

Relationship with Other Nutrients

The B complex of vitamins works as a team in carbohydrate metabolism, and deficiency of one can affect the whole process in a detrimental way. Because vitamin B6 deficiency is more likely than most of the other B vitamins, it should be a particular focus in making sure that this energy generation process occurs smoothly.

In particular, folic acid and vitamin B12 are intimately related to vitamin B6 in their core biochemical pathways. Each of these is a nutrient with potential for dietary deficiency, each can be prone to damage or absorption problems, and each comes from different food types. We get vitamin B12 from a relatively small number of foods (primarily animal and fermented foods), folic acid predominantly from vegetables and legumes, and vitamin B6 from many food groups. Enjoyment of food diversity is clearly an ideal way.

Every reaction in your body that uses vitamin B6 also uses magnesium as a mineral co-factor. Like vitamin B6, magnesium is a nutrient that many Americans fail to eat enough of on a regular basis. Tuna, spinach, and pumpkin seeds are all examples of foods rich in both vitamin B6 and magnesium. Our Chicken Breast With Honey-Mustard Sauce recipe contains more than the RDA for vitamin B6 and 85% of the requirement for magnesium.

Diets very high in protein are known to increase risk of vitamin B6 depletion. . For this reason, some researchers have suggested increased B6 when protein intake is especially high. For example, we have seen one research study in which researchers recommended nearly double the DRI for B6 with intake of 150 grams of protein per day by young women. Our conclusions from this research are two-fold: first, it does not make sense to consume excessive amounts of protein, unless specifically following a medical food regimen or under other specific health-related circumstances. Second, if you are consuming especially high levels of protein, it makes sense to take a closer look at your B6 intake and make sure that you are focusing on whole foods equally right in protein and B6.

Risk of dietary Toxicity

At amounts above the Tolerable Upper Intake Level (UL) of 100 mg per day, vitamin B6 has been reported to cause changes in sensation in the hands and feet. Given that even the 95th percentile of vitamin B6 intake in the U.S. is less than 10 mg per day,

reaching 100 mg on a regular basis from foods alone is very unlikely. In fact, every report of vitamin B6 toxicity that we can find involved the use of mega-dose supplementation. We find no reason to be concerned about the health effects of diets rich in vitamin B6, even when this dietary richness involves 200%-500% of the recommended DRI level.

Disease Checklist

- Premenstrual syndrome
- Fibrocystic breast disease
- Anemia
- Carpal tunnel syndrome
- Morning sickness
- Asthma
- High homocysteine
- Epilepsy
- Depression
- Seborrheic dermatitis
- ADHD

Public Health Recommendations

In 1998, the National Academy of Sciences established a set of Dietary Reference Intakes (DRI) that contained Recommended Dietary Allowances (RDA) for vitamin B6 by age and gender. These are summarized in the chart below. Note that the recommendations for infants under one year are Adequate Intake (AI) standards. The RDAs and AIs are as follows:

- 0-6 months: 0.1 mg
- 6-12 months: 0.3 mg
- 1-3 years: 0.5 mg
- 4-8 years: 0.6 mg
- 9-13 years: 1.0 mg
- 14-18 years, female: 1.2 mg
- 14-18 years, male: 1.3. mg
- 19-50 years, female: 1.3 mg
- 19-50 years, male: 1.3 mg
- 50+ years, female: 1.5 mg
- 50+ years, male: 1.7 mg
- Pregnant women: 1.9 mg
- Lactating women: 2.0 mg

The Tolerable Upper Intake Limit (UL) for vitamin B6 is set at 100 mg. Given that most foods contain less than a milligram of vitamin B6 per serving, reaching this level of intake without the use of supplements appears impossible. Intakes of vitamin B6 as high as 200-500% of the DRI still fall far below this UL guideline and have no research basis for any concern.

The Daily Value (DV) for vitamin B6 intake is 2 mg per day per 2000 calories. This is the value found on food labels.

As our WHFoods recommended daily intake level for B6, we chose the highest adult DRI level of 1.7 milligrams.

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The World's Healthiest Foods

World's Healthiest Foods rich in vitamin C		
Food	Cals	DRI/DV
Papaya	119	224%
Bell Peppers	29	157%
Broccoli	55	135%
Brussels Sprouts	56	129%
Strawberries	46	113%
Pineapple	83	105%
Oranges	62	93%
Kiwifruit	42	85%
Cantaloupe	54	78%
Cauliflower	29	73%

Basic Description

Vitamin C may be the most familiar of all of the nutrients. Although most adults would be hard pressed to name a good food source of biotin or riboflavin, most everyone can name citrus fruits as good sources of vitamin C. It is also a commonly used nutritional supplement.

The first use of modern scientific methods to assess disease treatment was when the British navy used foods containing vitamin C (although the vitamin itself would remain undiscovered for nearly two centuries) to prevent scurvy among sailors. You could make a good case that this nutrition experiment is among the most important scientific findings in human history.

Despite the familiarity of the U.S. public with vitamin C and the popularity of vitamin C supplements, food intake of vitamin C by the average U.S. adult is not much higher than the Dietary Reference Intake (DRI) level. For men in the U.S. twenty years and older, this average is 96 milligrams per day, and for women in the U.S. twenty years and older, it is 82 milligrams per day. (The DRIs for these two groups are 90 milligrams and 75 milligrams, respectively.) So even though U.S. adults are averaging adequate intake of vitamin C intake from their food, the amount is not as high as some people might expect given widespread familiarity and interest in vitamin C.

Of the World's Healthiest Foods, a staggering 27 rate as excellent sources of vitamin C. Six of these contain a full day's requirement of vitamin C in a single serving. We also rate 14 very good and 14 good sources of the vitamin. This should give you plenty of variety with which to build a menu plan that easily exceeds your vitamin C goal.

Role in Health Support

Protection Against Excess Free Radicals

Vitamin C is probably best known as an antioxidant. This is a word that we use frequently but don't always stop to think about in terms of its meaning. Antioxidants are forms of molecules that help keep chemical reactions in our body in check. In particular, antioxidants help prevent excessive activity on the part of free radical molecules. (Free radicals are forms of molecules that tend to be very reactive, and too many free radicals in the wrong place at the wrong time can do damage to our cells and tissue.) Vitamin C and other antioxidants help prevent that damage. Damage to the lens of the eye, damage to molecules circulating around in our bloodstream, and damage to genetic material (DNA) in our cells are all examples of damage that have been shown to be prevented under certain circumstances by vitamin C.

One interesting application of vitamin C as an antioxidant is its ability to transform iron into a state that is better absorbed in the intestine. Including vitamin C-rich foods in recipes with your best iron sources can potentially be a way to enhance iron absorption.

Collagen

Vitamin C is required to produce collagen, a protein that plays a critical role in the structure of our bodies. Collagen is the framework for our skin and our bones, and without it, we would quite literally fall apart.

This is exactly what we see with severe vitamin C deficiency, or scurvy. People who have this condition lose teeth, bleed easily, and lose the strength of their bones. Luckily, it doesn't take much vitamin C to prevent this problem. As we've known for more than two centuries, a single lime per day would usually be enough. (However, as described earlier, we have dozens and dozens of great food choices that will give us as much vitamin C as a single lime!)

Brain Health

Vitamin C is necessary to make certain neurotransmitters. These neurotransmitters are the signals that carry thoughts, feelings, and commands around our brains and throughout our nervous system.

In particular, we need vitamin C to produce serotonin, a hormone that plays a critical role in wide variety of body systems, including the nervous system, endocrine system, immune system, and digestive system. Many of our moods, daily bodily rhythms (including sleep-wake cycles), and experiences of stress and pain have serotonin included as a factor in their occurrence. Some of the most commonly used prescription medications for depression (SSRIs, or Selective Serotonin Reupdate Inhibitors) also target this hormone. While we are not suggesting that dietary intake of vitamin C will automatically improve the quality of any experiences described above, we do recommend that you include vitamin C-rich foods on a daily basis as part of your overall well-being.

Summary of Food Sources

Our best food sources of vitamin C have a single thing in common: they are all plant foods. Even though many—even most—animals make vitamin C in their bodies, only plants make it to the degree that they provide a rich source of the nutrient when eaten.

Probably most of you associate citrus fruits with vitamin C. This is not a myth—all of our listed citrus fruits (orange, grapefruit, lime, and lemon) are excellent sources of vitamin C.

Many non-citrus fruits are highly rated sources, as well. Papaya, strawberries, pineapple, kiwifruit, cantaloupe, and raspberries are also excellent vitamin C sources. Cranberries, blueberries, and watermelon are examples of very good sources, while apples, pears, and bananas are in the good category. You should expect almost any fresh fruit to be a good, very good, or excellentsource of dietary vitamin C.

In addition, many vegetables contain vitamin C. All of the greens on our website are excellent sources of vitamin C. We are big fans of green leafy vegetables as sources of many nutrients and encourage their inclusion in daily diets. Our 3-Minute Swiss Chard is an easy and tasty recipe to get you started.

Many of the cruciferous vegetables are excellent sources of vitamin C. These foods have many potential health benefits and are the focus of many of our recipes. Very good sources of vitamin C in the vegetable group include summer and winter squash, green beans, and carrots.

Our Herbs and Spices can also be very helpful in boosting your vitamin C intake. One WHFoods serving of parsley, for example, provides you with over half of our WHFoods recommended daily amount of vitamin C!

In case you are feeling lost in the flurry of good vitamin C sources, let's take a step back and make this easy. If you are getting two to three servings of fruit per day, and three to five servings of vegetables, you are almost certainly getting enough dietary vitamin C. If you find yourself worried, make sure you get a serving of fresh green leafy vegetables daily, since this amount will provide you with over one-third of the requirement in one sitting.

Introduction to Nutrient Rating System Chart

In order to better help you identify foods that feature a high concentration of nutrients for the calories they contain, we created a Food Rating System. This system allows us to highlight the foods that are especially rich in particular nutrients. The following chart shows the World's Healthiest Foods that are either an excellent, very good, or good source of vitamin C. Next to each food name, you'll find the serving size we used to calculate the food's nutrient composition, the calories contained in the serving, the amount of vitamin C contained in one serving size of the food, the percent Daily Value (DV%) that this amount represents, the nutrient density that we calculated for this food and nutrient, and the rating we established in our rating system. For most of our nutrient ratings, we adopted the government standards for food labeling that are found in the U.S. Food and

Drug Administration's "Reference Values for Nutrition Labeling." Read more background information and details of our rating system.

World's Healthiest Foods ranked as quality sources of vitamin C						
Food	**Serving Size**	**Cals**	**Amount (mg)**	**DRI/DV (%)**	**Nutrient Density**	**World's Healthiest Foods Rating**
Papaya	1 medium	118.7	168.08	224	34.0	excellent
Bell Peppers	1 cup	28.5	117.48	157	98.9	excellent
Broccoli	1 cup	54.6	101.24	135	44.5	excellent
Brussels Sprouts	1 cup	56.2	96.72	129	41.3	excellent
Strawberries	1 cup	46.1	84.67	113	44.1	excellent
Pineapple	1 cup	82.5	78.87	105	22.9	excellent
Oranges	1 medium	61.6	69.69	93	27.2	excellent
Kiwifruit	1 2 inches	42.1	63.96	85	36.5	excellent
Cantaloupe	1 cup	54.4	58.72	78	25.9	excellent
Cauliflower	1 cup	28.5	54.93	73	46.2	excellent
Kale	1 cup	36.4	53.30	71	35.1	excellent
Cabbage	1 cup	43.5	51.60	69	28.5	excellent
Bok Choy	1 cup	20.4	44.20	59	52.0	excellent
Grapefruit	0.50 medium	41.0	44.03	59	25.8	excellent
Parsley	0.50 cup	10.9	40.43	54	88.7	excellent
Turnip Greens	1 cup	28.8	39.46	53	32.9	excellent
Beet Greens	1 cup	38.9	35.86	48	22.1	excellent
Mustard Greens	1 cup	36.4	35.42	47	23.4	excellent
Collard Greens	1 cup	62.7	34.58	46	13.2	excellent
Raspberries	1 cup	64.0	32.23	43	12.1	excellent
Swiss Chard	1 cup	35.0	31.50	42	21.6	excellent
Tomatoes	1 cup	32.4	24.66	33	18.3	excellent
Lemons and Limes	0.25 cup	13.4	23.61	31	42.2	excellent
Spinach	1 cup	41.4	17.64	24	10.2	excellent
Asparagus	1 cup	39.6	13.86	18	8.4	excellent
Sea Vegetables	1 TBS	10.8	12.16	16	26.9	excellent
Fennel	1 cup	27.0	10.44	14	9.3	excellent
Thyme	2 TBS	4.8	7.68	10	38.0	excellent
Sweet Potato	1 cup	180.0	39.20	52	5.2	very good
Winter Squash	1 cup	75.8	19.68	26	6.2	very good
Green Peas	1 cup	115.7	19.56	26	4.1	very good
Blueberries	1 cup	84.4	14.36	19	4.1	very good
Cranberries	1 cup	46.0	13.30	18	6.9	very good
Watermelon	1 cup	45.6	12.31	16	6.5	very good
Green Beans	1 cup	43.8	12.13	16	6.7	very good
Summer Squash	1 cup	36.0	9.90	13	6.6	very good
Carrots	1 cup	50.0	7.20	10	3.5	very good
Plum	1 2-1/8 inches	30.4	6.27	8	5.0	very good
Garlic	6 cloves	26.8	5.62	7	5.0	very good
Basil	0.50 cup	4.9	3.82	5	18.8	very good
Dill	0.50 cup	1.9	3.78	5	47.5	very good
Romaine Lettuce	2 cups	16.0	3.76	5	5.6	very good
Potatoes	1 cup	160.9	16.61	22	2.5	good
Avocado	1 cup	240.0	15.00	20	1.5	good
Onions	1 cup	92.4	10.92	15	2.8	good

Banana	1 medium	105.0	10.27	14	2.3	good
Apple	1 medium	94.6	8.37	11	2.1	good
Pear	1 medium	101.5	7.65	10	1.8	good
Beets	1 cup	74.8	6.12	8	2.0	good
Leeks	1 cup	32.2	4.37	6	3.3	good
Apricot	1 whole	16.8	3.50	5	5.0	good
Celery	1 cup	16.2	3.13	4	4.6	good
Cucumber	1 cup	15.6	2.91	4	4.5	good
Peppermint	2 TBS	5.3	2.42	3	10.9	good
Cilantro	0.50 cup	1.8	2.16	3	28.2	good

World's Healthiest Foods Rating	Rule
excellent	DRI/DV>=75% OR Density>=7.6 AND DRI/DV>=10%
very good	DRI/DV>=50% OR Density>=3.4 AND DRI/DV>=5%
good	DRI/DV>=25% OR Density>=1.5 AND DRI/DV>=2.5%

Impact of Cooking, Storage and Processing

The same thing that makes vitamin C so important—its ability to protect against free radical damage—also makes it very prone to damage by heat, oxygen, and storage over time. In fact, the relative instability of vitamin C in foods presents a compelling argument in favor of fresh food dietary approaches like the one we advocate at World's Healthiest Foods.

The vitamin C content of food will start to decline as soon as it is picked, even though this decline can be slowed down and minimized by cooling and retention of the food in its whole form. But a fresh, vitamin C-rich vegetable like broccoli—if allowed to sit at room temperature for 6 days—can lose almost 80% of its vitamin C. That potential vitamin C loss is one of the reasons it is so important to store broccoli (and all other vitamin C-rich foods) according to the methods that we describe in our individual food profiles. All of our food profiles include sections on How to Select and Store, and for each food we provide you with exact storage times and conditions that will help minimize nutrient loss from each food.

Long-term storage of vegetables can cost a significant amount of vitamin C. Kept frozen for a year, kale can lose half its vitamin C or more. Canning is even more detrimental, with 85% of the original vitamin C lost over the same year.

While cooking will lower the amount of vitamin C in most foods, but the amount of vitamin C lost will vary widely by cooking method. For example, basket-steaming broccoli for 15 minutes will reduce the vitamin C content by nearly one quarter. That's one of the reasons why our WHFoods method for steaming broccoli never lasts longer than 5 minutes!

Risk of Dietary Deficiency

As described earlier, the average dietary intake for vitamin C in the United States is just above the Dietary Reference Intake (DRI) level for both adult men and adult women. From this standpoint, U.S. adults aren't at significant risk for vitamin C deficiency. However, average total calorie intake in the U.S. also tends to be too high, and while we may be doing okay in terms of our average vitamin C intake, we may also be overeating in order to do so. Whole, natural foods—especially fresh vegetables—can play a major role in providing ample vitamin C without increasing the risk of overeating. It's one of the reasons we recommend this food group so highly.

At the risk of oversimplifying, if you are eating multiple servings of fresh fruits and vegetables every day, you are very likely to be getting enough vitamin C.

Other Circumstances that Might Contribute to Deficiency

Since smoking increases free radical damage, smokers will need more dietary vitamin C. The National Academy of Sciences recommends that smokers get an extra 35 mg of vitamin C every day, about the amount found in one-half of a medium orange.

Relationship with Other Nutrients

Vitamin C can increase the absorption of iron (especially the iron found in plant foods) and may help lower the risk of dietary iron deficiency. You'll sometimes see us recommending the additional of a vitamin C-rich food to meals and recipes for this reason.

Antioxidants in foods tend to work together in important and synergistic ways to provide protection against free radical damage. The most well-known of these connections is that between vitamin E and vitamin C. Specifically, vitamin C helps to protect vitamin E in people, such as smokers, who have chronic overproduction of free radicals.

Similarly, we see the flavonoid class of plant-based antioxidants helping to make the free radical protection from vitamin C that much stronger. This is great news, given that the foods that are most flavonoid-rich also tend to be among our better vitamin C sources. This synergistic protection is but one of many potential explanations for why the health benefits of plant-based diets cannot be replicated by nutrient supplements.

A great example of vitamin C and flavonoids in a whole, natural food is fresh oranges. In this fruit, most of the vitamin C is found in the watery orange-colored portions, while many of the flavonoids are found in the white-colored linings and section dividers. (This distribution of vitamin C and flavonoids in oranges is one of the reasons that it can be helpful to consume the "pulp" along with the juice if you decide to consume a processed juice version of this food.)

Risk of dietary Toxicity

The National Academy of Sciences has established a Tolerable Upper Intake Level (UL) of 2000 mg per day for adults. While it is plausible that in rare situations—particularly with a rich intake of citrus juices—an individual could be above this UL from foods alone, we are not aware of any evidence to suggest that vitamin C intake from foods ever is responsible for toxicity symptoms.

Disease Checklist

- Common cold
- Scurvy
- Capillary fragility
- Asthma
- Gingivitis
- Gout
- Musculoskeletal injury
- High blood pressure
- Seasonal allergies
- Smoking

Public Health Recommendations

In 2000, the National Academy of Sciences released a set of Dietary Reference Intakes (DRI) for vitamin C that included a range of Recommended Dietary Allowances (RDA) by age and gender. These are summarized in the chart below. (Note that the recommendations for infants under age one are Adequate Intake (AI) standards.)

- 0-6 months: 40 mg
- 6-12 months: 50 mg
- 1-3 years: 15 mg
- 4-8 years: 25 mg
- 9-13 years: 45 mg
- 14-18 years, female: 65 mg
- 14-18 years, male: 75 mg
- 19+ years, female: 75 mg
- 19+ years, male: 90 mg
- Pregnant women, 14-18 years: 80 mg
- Pregnant women, 19+ years: 85 mg
- Lactating women, 14-18 years: 115 mg

- Lactating women, 19+ years: 120 mg

The 2000 DRI report also included a Tolerable Upper Intake Level (UL) for vitamin C of 2000 mg for adults. Although the report does not draw a distinction between dietary vitamin C and supplements, it would be hard to routinely go above this UL from food alone.

According to the DRI, smokers require extra vitamin C, and should add 35 mg to their daily RDA from the chart above. You'd find those 35 mg in a single serving of beet or mustard greens.

The Daily Value (DV) of vitamin C that you'll see on food labels is 60 mg.

We adopted 75 milligrams per day—the DRI for adult women 19 years and older—as our WHFoods recommended daily intake level for vitamin C.

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The World's Healthiest Foods

World's Healthiest Foods rich in vitamin D		
Food	Cals	DRI/DV
Salmon	158	128%
Sardines	189	44%
Tuna	147	23%
Cow's milk	74	16%
Eggs	78	11%
Mushrooms, Shiitake	41	5%

Basic Description

Vitamin D is one of the most intensely studied yet widely debated nutrients in health research over the past decades. The research debate over vitamin D has focused partly on its roles in the body, and more recently on its optimal levels in the body and on the relationship of those levels to dietary intake.

Since vitamin D was first recommended as an essential nutrient for the U.S. public in 1943, recommendation levels for this nutrient have varied. Originally, recommended intake for vitamin D by the National Academy of Sciences was approximately 200 IU (5 micrograms of cholecalciferol). Over the years, this level had gradually been increased to 400 IU (10 micrograms of cholecalciferol) as the current Daily Value (DV) set forth by the U.S. Food and Drug Adminstration (FDA), and to current recommendation levels of 400-800 IU (10-20 micrograms of cholecalciferol) by the National Academy of Sciences. (At WHFoods, we use the DV of 400 IU as our recommended daily intake level.) However, this recommended daily intake level remains controversial for three basic reasons.

First is the long-known fact that human skin cells can make vitamin D from sunlight. When certain wavelengths of ultraviolet B (UVB) light from the sun land on our skin cells, a molecule in our skin cells called 7-dehydrocholesterol can be converted into a preliminary form of vitamin D called cholecalciferol. However, the exact amount of cholecalciferol that gets made is difficult to predict! The number of pigments in our skin cells, the strength of the UVB light, the overall health of our skin, and other factors impact this set of events. (One of these other factors, for example, involves use of sunscreen and general skin products containing UVB-blocking agents.) In other words, even though we know that our skin cells can make this preliminary form of vitamin D from sunlight, it is not easy for us to predict how much will get made.

Second is our knowledge that cholecalciferol from our skin cells is not the same as fully active vitamin D. Fully active vitamin D requires two additional steps. First is transfer of cholecalciferol in the bloodstream from our skins cells to our liver cells. This transfer is required in order for our liver cells to produce 25-hydroxycholecalciferol or 25(OH)D. Second is the transfer of 25(OH)D in the bloodstream from our liver cells to our kidney cells. This second transfer allows our kidney cells to take 25(OH)D and convert it into 1,25-dihydroxycholecalciferol, or 1,25(OH)D. It's this more complicated form of vitamin D that is active as a regulator of certain immune system activities. In short: the role of our liver cells and kidney cells in creating fully active vitamin D adds further complications when researchers try to predict vitamin D status.

Finally, recommended daily intake of vitamin D is controversial because scientists aren't certain about the relationship between blood levels of this vitamin and disease risk. Early studies on vitamin D and disease often focused on prevention of rickets (a disease involving bone formation related to deficiency of vitamin D and bone-related minerals). Recent studies on vitamin D and disease have focused on many health problems not specific to bone, including problems involving our immune, cardiovascular, and blood sugar regulating systems. As vitamin D research has expanded in scope, researchers have been less certain about optimal amounts of vitamin D necessary to prevent unwanted problems in these many body systems.

Of the World's Healthiest Foods, we list one excellent, two very good, and three good sources of vitamin D. Needless to say, this is a much shorter list than we see with other nutrients and will present a challenge to the goal of meeting needs with diet alone. Luckily, however, unlike other nutrients, vitamin D is a nutrient that we have the opportunity to increase by increasing our exposure to sunlight, and for some people, this combination of diet-plus-sunlight might provide an acceptable amount of this vitamin. As we point out later in this profile, however, many people will want to consult with their healthcare provider when making decisions about vitamin D status.

Role in Health Support

Bone Health

Vitamin D deficiency can lead to softening or malformation of bone. In children, this condition is called rickets. In adults, it is called osteomalacia.

The relationship between vitamin D and bone metabolism is more complicated than you might guess. As a hormone, vitamin D acts to increase calcium in the blood stream. The first two ways it accomplishes this are by increasing your ability to absorb calcium from foods and by reducing the amount of calcium you lose in the urine. The last way, however, is by pulling calcium from the bone to support your blood levels.

Obviously, if our goal is to promote strong bones, we don't want to be pulling calcium from them into the blood stream. For this reason, we only consider vitamin D to be a helpful bone builder when there is sufficient dietary calcium. Any bony fish, including sardines or canned salmon, would potentially be a rich source of both vitamin D and calcium. Check our calcium profile to learn more about dietary calcium.

Blood Sugar Control

Researchers have known for some time that the risk of high blood sugar and diabetes are higher in people with low vitamin D levels. More recent research has demonstrated that bringing these levels back up to normal can help reverse some of the risk. Although research has not been entirely consistent, it is becoming more accepted that vitamin D deficiency is a risk factor for developing diabetes.

Immunity

Vitamin D is one of many hormones involved in the maturation of white blood cells, our first line against most types of infection. In particular, researchers have uncovered a relatively consistent link between low vitamin D level and increased risk of respiratory infection. This research is still relatively new, and we do not know at this point whether increasing dietary intake will reverse this correlation.

Summary of Food Sources

The conversation about which foods contain vitamin D can be a bit challenging because the WHFoods list for vitamin D is quite short. Furthermore, one of the best dietary sources of vitamin D (milk) is only vitamin D-rich because of fortification that occurs at the time of processing. (While whole milk from grass-fed cows with plenty of time spent outdoors does contain vitamin D, we have not seen studies documenting predictable levels of vitamin D in non-fortified, grass-fed whole milks.) For all of these reasons, it requires very special effort for people who are reliant on foods alone (versus sun exposure) to reach their daily vitamin D needs.

It can be done, however. It is easiest to do if you like fish. Salmon, for instance, contains more than the Daily Value (DV) in just a single serving. Sardines contain over 40% of the DV, and tuna contains just under 25%.

Pasture-raised eggs are a good source of dietary vitamin D, with about 10% of the DV per egg. The vitamin D is concentrated in the yolk, so you'll need to eat the whole egg to get it. Some mushroom species, including shiitakes, contain as much as 5% of the DV.

The biggest sources of vitamin D in the American diet are not whole natural foods, however, but fortified, processed foods. Virtually all commercial cow's milk sold in the U.S. has been fortified for vitamin D in the amount of 100% DV per quart (meaning that each 8 ounce glass contains a little over one quarter of the DV). At one time, there had been a big problem with these fortification programs including too much or too little vitamin D, but recent surveys confirm they now contain a more predictable level. If you enjoy cow's milk and do well with this food, it can make an outstanding contribution to your vitamin D intake. Our recommended form of cow's milk is grass-fed, and if cows have had ample access to the outdoors and sunlight, their milk may contain vitamin D even if non-fortified. One additional note here: cholecalciferol is the form of vitamin D3 used in milk fortification.

If you regularly include and enjoy processed foods in your meal plan, we would also point out that fortified breakfast cereals and fortified juices can make a contribution to your vitamin D intake, since these foods are often fortified with vitamin D at various levels. However, we do not think that it makes sense to add processed foods to your meal plan if your primary goal is

increasing your vitamin D intake. If you are concerned about your vitamin D intake level from whole, natural foods, we recommend that you consult with your healthcare provider and determine whether supplemental vitamin D makes sense, and in what amount.

Introduction to Nutrient Rating System Chart

In order to better help you identify foods that feature a high concentration of nutrients for the calories they contain, we created a Food Rating System. This system allows us to highlight the foods that are especially rich in particular nutrients. The following chart shows the World's Healthiest Foods that are either an excellent, very good, or good source of vitamin D. Next to each food name, you'll find the serving size we used to calculate the food's nutrient composition, the calories contained in the serving, the amount of vitamin D contained in one serving size of the food, the percent Daily Value (DV%) that this amount represents, the nutrient density that we calculated for this food and nutrient, and the rating we established in our rating system. For most of our nutrient ratings, we adopted the government standards for food labeling that are found in the U.S. Food and Drug Administration's "Reference Values for Nutrition Labeling." Read more background information and details of our rating system.

World's Healthiest Foods ranked as quality sources of vitamin D						
Food	**Serving Size**	**Cals**	**Amount (IU)**	**DRI/DV (%)**	**Nutrient Density**	**World's Healthiest Foods Rating**
Salmon	4 oz	157.6	511.43	128	14.6	excellent
Sardines	3.20 oz	188.7	175.09	44	4.2	very good
Cow's milk	4 oz	74.4	62.22	16	3.8	very good
Tuna	4 oz	147.4	92.99	23	2.8	good
Eggs	1 each	77.5	43.50	11	2.5	good
Mushrooms, Shiitake	0.50 cup	40.6	20.30	5	2.2	good

World's Healthiest Foods Rating	Rule
excellent	DRI/DV>=75% OR Density>=7.6 AND DRI/DV>=10%
very good	DRI/DV>=50% OR Density>=3.4 AND DRI/DV>=5%
good	DRI/DV>=25% OR Density>=1.5 AND DRI/DV>=2.5%

Impact of Cooking, Storage and Processing

Vitamin D is a very stable nutrient in foods. It will not be significantly damaged by most low-heat cooking techniques.

You can expect to lose a little more vitamin D from foods cooked in oil. (Of course, frying in oil at higher temperatures is not a cooking methond that we recommend at WHFoods.) Fried eggs lose about 20% of their vitamin D, compared to only 10% lost in the poaching process. Either way, however, you should expect most of the vitamin D to end up on your plate.

There is some confusion about how well vitamin D stands up to high-heat cooking techniques. One research group found that vitamin D in cheese baked at 450° F (232°C) for 10 minutes lost very little vitamin D. Another study reported that eggs baked at 325°F (163°C) for 40 minutes lost over half the original vitamin D content. One way to avoid potentially unwanted loss of vitamin D based on information from these mixed studies would be to avoid higher heats and lengthy baking times. We do just that in all of our recommended cooking methods at WHFoods.

Risk of Dietary Deficiency

The risk of dietary deficiency of vitamin D is substantial. In every age and gender group surveyed, average American diets fail to meet or exceed the Daily Value (DV) for vitamin D, even when supplements and fortified foods are included in the analysis. When we eliminate supplements, and look at dietary intake alone, we see that less than 5% of Americans meet the DV, and in many age groups it is less than 1%. Because fortified foods—foods containing vitamin D added during processing—make up 60% of our dietary vitamin D, eliminating them from dietary analysis would make this outcome even worse.

Because vitamin D can be obtained from the sun as well as from the diet, researchers have usually preferred to estimate deficiency from blood levels of the vitamin. According to a nationally representative random sample of Americans, 13% are deficient in vitamin D and another 30% have a marginal blood level.

Even worse, vitamin D deficiency appears to be on the rise, with rates of deficient blood levels tripling since the 1980s. This trend is probably related more to reduced sun exposure and widespread use of sunscreen than changes in dietary habits.

With most of the nutrients we discuss here at the World's Healthiest Foods, it is very easy for us to construct a daily diet that easily meets your daily needs. A very small number of nutrients require some special focus on specific foods to maintain a good supply. Then, there's vitamin D.

Vitamin D is a nutrient particularly dependent on specific foods and food groups. You'll have to regularly consume foods from these groups to meet to your daily needs. From our perspective at WHFoods, a dietary approach to keeping vitamin D intake over the DV would typically focus on routine fish intake—especially higher-fat fish like salmon. Other whole foods that would be logical to consider include eggs, mushrooms, grass-fed cow's milk, or whole food-based products that have been fortified with vitamin D (for example, D-fortified grass-fed milk, grass-fed yogurt or cheese).

If this nutrient is of special concern to you, we recommend that you consult with your healthcare provider for help in determining your vitamin D needs and the best approach for meeting them. Laboratory testing for vitamin D blood levels and gene testing for vitamin D metabolism are widely available from many healthcare providers.

Other Circumstances that Might Contribute to Deficiency

Unlike most other nutrients, there is more to the story here than dietary intake of vitamin D. The adequacy of our dietary intake of vitamin D is substantially related to our natural sunlight exposure. Unfortunately, variability in where we live and the tone of our skin make it impossible to give a single and clear recommendation about how much sun exposure is required.

The further north you are, the less likely you are to meet your vitamin D needs. In the continental U.S., if you live north of the 37th parallel (roughly where San Francisco, California and Richmond, Virginia are), you should expect to make little vitamin D from natural sunlight during the winter months. In addition, the farther north you go, the less vitamin D you are likely to make from winter sunlight partly due to longer periods of wintertime. The darker your skin, the less efficiently you produce vitamin D. For this reason, African-Americans have on average about half the blood level of vitamin D when compared to ethnicities with lighter skin tones.

Sunscreen interferes with the production of vitamin D in the skin. Researchers have been debating about how deep this reduction is. One research group found that application of SPF8 sunscreen as recommended (which most people fail to do) completely blocked any production of vitamin D with sun exposure.

We have seen calculators online that use your skin tone and latitude to predict the amount of sun exposure you'll need to achieve sufficient levels of vitamin D without dietary intake. As long as you understand that these provide very rough estimates, we support their use to help you determine your vitamin D needs.

Relationship with Other Nutrients

As described above, vitamin D and calcium are very closely related in activity. Deficiency of either can lead to impaired bone formation, and deficiency of both in tandem is a common public health problem due to the amount of processed and unhealthy food in the American diet. As described above, there is even reason to believe that vitamin D in the absence of adequate calcium could cause you to lose bone by increasing the rate of bone loss.

Vitamin D also appears to slightly increase the absorption of magnesium in the intestine, but not to nearly the same degree that we see it increase calcium absorption. In fact, because calcium and magnesium compete with each other for absorption, we are concerned about magnesium deficiency as a potential consequence of widespread medical treatments focusing on calcium and vitamin D supplementation.

Vitamin D and vitamin K work together to help keep the rate of bone production and breakdown in balance. Low vitamin K levels are only starting to be understood as a risk for bone problems, so our knowledge in this area is much less complete compared to vitamin D.

Risk of dietary Toxicity

The Tolerable Upper Intake Level (UL) for vitamin D is 4000 IU for adults. Given that it is a struggle for many people to reach the 400 IU Daily Value, it appears very difficult to regularly go above the UL from diet alone. Using our top vitamin D food as an example, you'd have to eat just under 2 pounds of salmon per day to be at the UL.

We would like to make one additional note on dietary toxicity of vitamin D and the UL of 4,000 IU. In certain clinical situations, it is clear to us that some individuals may need to exceed the dietary UL via vitamin D supplementation in order to promote optimal health. Once again, if you have a particular concern about vitamin D and your own health, we encourage you to meet with your healthcare provider to determine the best steps to take.

Disease Checklist

- Osteoporosis
- Rickets
- Osteomalacia
- Loss of balance
- Diabetes
- Rheumatoid arthritis
- Asthma
- Depression
- Epilepsy
- Low immune function

Public Health Recommendations

In 2010, the National Academy of Sciences updated the Dietary Reference Intakes (DRI) for vitamin D. This DRI update included a set of Recommended Dietary Allowances (RDA) which are summarized in the chart below. Note that the recommendations for infants under one year are Adequate Intake (AI) standards. The RDAs and AIs are as follows:

- 0-12 months: 400 IU (10 micrograms of cholecalciferol)
- 1-70 years: 600 IU (15 micrograms of cholecalciferol)
- 70+ years: 800 IU (20 micrograms of cholecalciferol)
- Pregnant women: 600 IU (15 micrograms of cholecalciferol)
- Lactating women: 600 IU (15 micrograms of cholecalciferol)

These RDA recommendations are meant to prevent symptoms related to deficiency even in those with minimal sunlight exposure.

The DRI update also included a Tolerable Upper Intake Limit (UL) of 4000 IU for vitamin D.

A Daily Value (DV) of 400 IU (10 micrograms of cholecalciferol) is the standard you will see on food and supplement labels. It is also the daily recommended amount that we use for all of our calculations at WHFoods, including our food rating system.

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The World's Healthiest Foods

World's Healthiest Foods rich in vitamin E		
Food	Cals	DRI/DV
Sunflower Seeds	204	82%
Almonds	132	40%
Spinach	41	25%
Swiss Chard	35	22%
Avocado	240	21%
Peanuts	207	20%
Turnip Greens	29	18%
Asparagus	40	18%
Beet Greens	39	17%
Mustard Greens	36	17%

Basic Description

Vitamin E is a blanket term for eight different naturally occurring nutrients—four different tocopherols and four different tocotrienols. Each of these vitamin E types is considered a fat-soluble antioxidant, and all eight are found in varying degrees in our daily diet. You may sometimes hear all eight molecules being referred to collectively as "tocochromanols."

The most famous of the vitamin E group is alpha-tocopherol. Both with respect to diet and high-dose supplementation, it is among the most intensely studied of nutrients. This is because its ability to help prevent free radical damage is well documented Public health recommendations for vitamin E are typically measured in milligram equivalents of alpha-tocopherol equivalents, or mg ATE. You will find this abbreviation being used throughout our live website charts.

However, despite the current prominence of alpha-tocopherol in public health recommendations and nutrition research, scientists are also interested in potential health benefits associated with lesser studied members of the vitamin E family, especially the tocotrienols. Like tocopherols (including alpha-tocopherol), tocotrienols are naturally occurring forms of vitamin E. Since they cannot be converted by humans into alpha-tocopherol, the tocotrienols are not considered relevant in meeting vitamin E needs. However, preliminary studies suggest that tocotrienols can provide us with health benefits in a way that is distinct from alpha-tocopherol, as well as other tocopherols. We look forward to future research in this area.

In this introductory description of vitamin E, it is also worth mentioning the unusually confusing nature of its units of measurement. There is really no such thing as "milligrams of vitamin E" since this description fails to explain what forms of the vitamin were considered when making the determination. As mentioned earlier, our website chart present vitamin E data in terms of "mg ATE" which stands for "milligrams of alpha-tocopherol equivalents." However, other types of equivalents can be used in presenting vitamin E data. For example, equivalents of d-alpha-tocopheryl acetate and equivalents of d-alpha-tocopheryl succinate can be used. (These two chelated, synthetic forms of vitamin E are frequently found in dietary supplements due to their longer shelf life).

While many of the World's Healthiest Foods are rich in vitamin E, we see that average U.S. adults fail to come close to a minimal requirement for this important nutrient. Below, we'll give you some guidance to help you chose foods rich in vitamin E that will better help you meet your daily needs.

You'll have a number of foods to choose from to build a menu that is rich in vitamin E. We list seven of the World's Healthiest Foods as excellent sources of vitamin E. Another six foods rate as very good sources, while twelve foods are listed as good.

Role in Health Support

Protection Against Free Radical Damage

Vitamin E is a potent antioxidant. Because it is fat soluble, we see it offer protection against damage to the fats that line the outside of every cell of our body.

When the fats in our membranes become damaged, important cell functions become compromised. Based on this important mechanism, researchers have studied whether diets low in vitamin E are associated with many diseases associated with aging.

We also see vitamin E protect fats from free radical damage *before* we eat them. We'll talk about the role of vitamin E in protecting foods during storage below in the Impact of Cooking, Storage, and Processing section.

Protection Against Heart Disease

Vitamin E helps protect LDL cholesterol (sometimes referred to as "bad" cholesterol) from free radical damage. Free radical damage typically involves an unwanted interaction with a reactive oxygen-containing molecule. When vitamin E is deficient—and under some other circumstances as well—it is possible for LDL cholesterol to become insufficiently protected and damaged by oxygen. When damaged in this way, the LDL cholesterol is often referred to as "oxidized LDL." If the process continues, it is possible for oxidized LDL to accumulate in blood vessel walls and create the early stages of hardening of the arteries (atherosclerosis).

Diets rich in vitamin E from vegetables, fish, and plant oils—like the Mediterranean diet for example—have been linked to cardiovascular prevention in large health surveys. Understand, though, that the potential benefits of this diet are not limited to or fully explained by vitamin E, and that dietary supplements of vitamin E (in comparison to vitamin E in food) have not demonstrated the same sort of preventive benefit that researchers hoped to see.

Summary of Food Sources

Of our seven excellent sources of vitamin E, five are green leafy vegetables. Followers of our WHFoods site will probably not be surprised by this—green leafy vegetables score well as sources of many different nutrients. With respect to vitamin E, their combination of nutrient richness and low calories is very compelling to our rating system. Expect each serving of greens to contain about 15 to 25% of your daily requirement.

Outside of greens, the foods with the most vitamin E tend to be high fat foods. These include nuts, seeds, extracted oils, and fatty fish. The amount of vitamin E per serving of nuts or seeds can vary widely, but you should expect to receive at least about 10% of your daily need, and sometimes as much as 80% (as we see with sunflower seeds).

Many oil rich-plants give us good amounts of vitamin E. These include olives and avocados, both of which provide between 10-15% of your daily need. Because these oily foods contain more calories, we rate them as good rather than very good or excellent sources. Still, we encourage using these plants or plant oils to help provide vitamin E.

We see a few of our World's Healthiest seafoods are rich sources of vitamin E. Shrimp and sardines are two examples of this, with each topping 10% of daily requirements. Salmon and cod contain a little less vitamin E, yet can still be solid contributors.

Because most U.S. residents fail to get enough vitamin E in their daily diet, we recommend paying some attention to food sources of this important antioxidant. As long as you make a few of these vitamin E rich foods staple foods in your daily diet, you should be able to meet your intake requirements through foods alone..

Perhaps the easiest way to make sure you are getting enough vitamin E is by including sunflower seeds as snacks or as part of meals. This recipe for Healthy Turkey Salad contains nearly the whole Dietary Reference Intake (DRI) in one meal. Here are a few more recipes—Pureed Sweet Peas and 5-Minute Collard Greens with Sunflower Seeds—that include sunflower seeds.

We can also rely on meals that contain multiple foods providing more modest amounts of vitamin E, and allow them to stack up to become a more substantial amount. Our Poached Eggs Over Spinach and Mushrooms recipe contains spinach, eggs, and olive oil as sources of vitamin E. Together, they provide one-third of the RDA in only 10% of your daily calorie intake.

Recipes that contain nuts and nut butters will be a nice way to add vitamin E into your meals. You can be creative in the way you do this; for example, our 10-Minute Apricot Bars is a dessert recipe that provides more than 40% of the RDA for vitamin E.

There is a balance between getting plenty of fat-rich foods as sources of vitamin E and overdoing it and letting the calories pile up. As long as you choose wisely, you should be able to cover your vitamin E needs with just a few rich sources.

Introduction to Nutrient Rating System Chart

In order to better help you identify foods that feature a high concentration of nutrients for the calories they contain, we created a Food Rating System. This system allows us to highlight the foods that are especially rich in particular nutrients. The following chart shows the World's Healthiest Foods that are either an excellent, very good, or good source of vitamin E. Next to each food name, you'll find the serving size we used to calculate the food's nutrient composition, the calories contained in the serving, the amount of vitamin E contained in one serving size of the food, the percent Daily Value (DV%) that this amount represents, the nutrient density that we calculated for this food and nutrient, and the rating we established in our rating system. For most of our nutrient ratings, we adopted the government standards for food labeling that are found in the U.S. Food and Drug Administration's "Reference Values for Nutrition Labeling." Read more background information and details of our rating system.

World's Healthiest Foods ranked as quality sources of vitamin E						
Food	**Serving Size**	**Cals**	**Amount (mg (ATE))**	**DRI/DV (%)**	**Nutrient Density**	**World's Healthiest Foods Rating**
Sunflower Seeds	0.25 cup	204.4	12.31	82	7.2	excellent
Spinach	1 cup	41.4	3.74	25	10.8	excellent
Swiss Chard	1 cup	35.0	3.31	22	11.3	excellent
Turnip Greens	1 cup	28.8	2.71	18	11.3	excellent
Asparagus	1 cup	39.6	2.70	18	8.2	excellent
Beet Greens	1 cup	38.9	2.61	17	8.1	excellent
Mustard Greens	1 cup	36.4	2.49	17	8.2	excellent
Chili Peppers	2 tsp	15.2	2.06	14	16.2	excellent
Almonds	0.25 cup	132.2	6.03	40	5.5	very good
Broccoli	1 cup	54.6	2.26	15	5.0	very good
Bell Peppers	1 cup	28.5	1.45	10	6.1	very good
Kale	1 cup	36.4	1.11	7	3.7	very good
Tomatoes	1 cup	32.4	0.97	6	3.6	very good
Avocado	1 cup	240.0	3.11	21	1.6	good
Peanuts	0.25 cup	206.9	3.04	20	1.8	good
Shrimp	4 oz	134.9	2.49	17	2.2	good
Olives	1 cup	154.6	2.22	15	1.7	good
Olive Oil	1 TBS	119.3	1.94	13	2.0	good
Collard Greens	1 cup	62.7	1.67	11	3.2	good
Cranberries	1 cup	46.0	1.20	8	3.1	good
Raspberries	1 cup	64.0	1.07	7	2.0	good
Kiwifruit	1 2 inches	42.1	1.01	7	2.9	good
Carrots	1 cup	50.0	0.81	5	1.9	good
Green Beans	1 cup	43.8	0.56	4	1.5	good
Leeks	1 cup	32.2	0.52	3	1.9	good

World's Healthiest Foods Rating	Rule
excellent	DRI/DV>=75% OR Density>=7.6 AND DRI/DV>=10%
very good	DRI/DV>=50% OR Density>=3.4 AND DRI/DV>=5%
good	DRI/DV>=25% OR Density>=1.5 AND DRI/DV>=2.5%

Impact of Cooking, Storage and Processing

The vitamin E in foods degrades slowly over time. For example, at room temperature, wheat flour loses about one-third of its vitamin E at close to one year of storage. That said, most people would be making use of their wheat flour long before this year-long time period.

Similarly, olive oil kept in a closed bottle will lose about 20-30% of its vitamin E over six months of storage. Don't leave the bottle open, though, as all of the vitamin E will be gone after three or four months if you do. (While leaving olive oil in an opened bottle might sound unlikely, there are a good number of olive oil containers in the marketplace that feature an unsealed spout, and we do not recommend storage of olive oil in this way. You will find many more details about olive oil storage in our Extra Virgin Olive Oil food profile.)

Vitamin E also gets damaged by high heat cooking. For example, heating olive oil at 340°F (172°C) will lead to a destruction of the vitamin E, with almost half lost at three hours, and almost all of it gone by six hours. At WHFoods, we do not generally recommend any heating of extra virgin olive oil, and if we do include it in a heated sauce or other recipe, we heat it very gently and briefly. The delicate nature of vitamin E, and the fatty acids it protects, are good reasons to avoid heating of this oil. We adopt a similar approach for oil-rich foods like nuts and seeds, which we recommend be consumed in raw or minimally cooked form.

Usually in this section of our nutrient profiles, we discuss how specific nutrients are damaged in the storage of foods. But with respect to vitamin E, it is equally important to note that this nutrient can protect the foods from damage. For example, meat from chickens fed diets high in vitamin E show less evidence for free radical damage to their fats over 10 days of storage. Presumably, this vitamin E richness in the food consumed by the chickens helped protect their body fat from damage by oxygen. (We don't have research comparing the human health consequences of consuming chicken fat with and without varying degrees of free radical damage. But we do know that animals fed diets that are rich in vitamin E typically provide us with animal foods that have good amounts of this vitamin as well.)

Risk of Dietary Deficiency

Given that the average U.S. adult eats exactly half the Dietary Reference Intake (DRI) for vitamin E—7.5 mg of the recommended 15 mg per day—the risk of dietary deficiency of vitamin E in the United States is substantial. In fact, vitamin E is one of the most common vitamin deficiencies in the United States, with as many as 92% of men and 98% of women failing to reach target intake goals.

In 2006, a research group from Tufts University did a statistical model of the best way to ensure vitamin E nutrition while staying within normal calorie levels and without impairing other nutrient intake. Among their conclusions, they asserted that a low intake of nuts and seeds—70% of their subjects didn't eat any of either—was predictive of low vitamin E intake. Analyzing this conclusion in reverse, this is further evidence that nuts and seeds can be a good place to start when trying to achieve strong vitamin E nutrition. (Of course, low intake of dark green leafy vegetables by the average U.S. adult is another reason why so many people in the U.S. fail to meet their vitamin E needs.)

At first, it may seem like a paradox that we tend to eat diets high in fat, yet fail to have reliable vitamin E nutrition. That's because not every type of dietary fat is as rich in vitamin E as nuts or seeds. The way plant cooking oils are manufactured and processed can lead to significant destruction of the nutrient before it ever gets to your plate. Generally speaking, you should expect highly processed foods (e.g., oils made from nuts and seeds) to contain less vitamin E than their whole, natural counterparts (e.g., whole nuts and seeds).

Other Circumstances that Might Contribute to Deficiency

Diets that overly restrict fat can limit vitamin E intake substantially. It will not be impossible to achieve vitamin E nutrition with a very low fat diet, but you'll need to work much harder to do it. For example, if you decided that you wanted to get 100% of your DRI for vitamin E from sunflower seeds alone—our richest WHFoods source—you would need to allow for 18 grams of fat in your day's food just to provide that amount. In an 1,800-calorie meal plan, that amount of fat would represent 9% of total calories all by itself. If you consumed an additional 18 grams of fat from all of the rest of your foods on that day, you diet for that day would already be close to 20% fat. On the other hand, if you were willing to obtain your vitamin E exclusively from dark green leafy vegetables, you could get 100% of the DRI from about 5 cups, representing 150-200 calories but only 2-5 grams of fat.

Any disease or medication that impairs the ability to digest fats will also endanger vitamin E nutrition. If this potentially describes you, make sure to talk to your doctor to make sure that you are protected against deficiency.

Relationship with Other Nutrients

Diets high in polyunsaturated fats—the type found in most fish and vegetable oils—may increase your requirement for vitamin E. Some sources recommend an older standard of an extra 0.6 mg of vitamin E for each gram of polyunsaturated fat. We are

not convinced that this level of specificity is well supported, even though the principle of increasing vitamin E intake along with increased intake of polyunsaturated fat makes good sense to us. The World's Healthiest Foods recipes tend to be moderate in polyunsaturated fats (and much higher in the more stable monounsaturated fats than most U.S. diets), and as such, we believe that our WHFoods recommendation of 15 milligrams of d-alpha-tocopherol equivalents per day should suffice for the average person.

Like other dietary antioxidants, vitamin E needs help from multiple nutrients to do its job at maximum efficiency. In particular, vitamin C helps to recycle vitamin E so it can continue to neutralize free radicals over and over again.

If vitamin K levels are low, too much vitamin E can lead to problems involving too easy bleeding from injuries and too slow closing of wounds. The amounts of vitamin E necessary to create this effect are large, however, and probably not achievable via diet alone. (In other words, dietary supplementation of vitamin E would most likely be required to create this degree of imbalance between vitamin E and vitamin K.)

Risk of dietary Toxicity

We are not aware of a single published report of adverse effects from dietary vitamin E. Reflecting this lack of evidence for harm, the National Academy of Sciences set the Tolerable Upper Intake Limit (UL) for vitamin E at 1000 mg, more than 60 times the DRI, and more than 100 times what an average American eats in a day. You can feel confident that you are not eating toxic levels of vitamin E in your daily diet. Translated into IU, 1,000 milligrams of vitamin E represents 1,490 IU of d-alpha-tocopherol and 1,360 IU of d-alpha-tocopheryl acetate.

Disease Checklist

- Cancer
- Heart attack
- Stroke
- PMS
- Fibrocystic breast disease
- Diabetes
- Epilepsy
- Alzheimer's disease
- Parkinson's disease
- Macular degeneration
- Cataract
- Intermittent claudication
- Cold sores
- Immune health

Public Health Recommendations

In 2000, the National Academy of Sciences established a set of Dietary Reference Intakes (DRIs) for vitamin E. These recommendations included Adequate Intake (AI) levels for infants under one year of age, and Recommended Dietary Allowances (RDAs) for everyone else. These milligrams amounts represent alpha-tocopherol equivalents, or mg ATE. DRIs for vitamin E are as follows:

- 0-6 months: 4 mg
- 6-12 months: 5 mg
- 1-3 years: 6 mg
- 4-8 years: 7 mg
- 9-13 years: 11 mg
- 14+ years: 15 mg
- Pregnant women: 15 mg
- Lactating women: 19 mg

The most common DRI for vitamin E—15 milligrams ATE (alpha-tocopherol equivalents) —translates into approximately 22 IU of d-alpha-tocopherol and 20 IU of d-alpha-tocopheryl acetate. We adopted this amount as our recommended intake level at WHFoods. (The form of d-alpha-tocopherol is a naturally occurring form of vitamin E that is chemically classified as "non-esterified" and d-alpha-tocopheryl acetate is an esterified form commonly found in supplements due to its longer shelf life.)

The 2000 DRI recommendations also included a Tolerable Upper Intake Limit (UL) for adults of 1000 mg per day. As discussed above, this is more than an order of magnitude beyond even what the most vitamin E-rich diet could ever contain. For this reason, we should consider this UL more for supplement intake than guidance around dietary choices. Translated into IU, 1,000 milligrams of vitamin E represent 1,490 IU of d-alpha-tocopherol and 1,360 IU of d-alpha-tocopheryl acetate.

The Daily Value (DV) for vitamin E is 30 IU. The measurement of IU, short for International Units, is an older way to quantify vitamin E with 1 milligram of d-alpha-tocopherol from food equivalent to 1.49 IU.

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The World's Healthiest Foods

World's Healthiest Foods rich in vitamin K		
Food	Cals	DRI/DV
Kale	36	1180%
Spinach	41	987%
Mustard Greens	36	922%
Collard Greens	63	858%
Beet Greens	39	774%
Swiss Chard	35	636%
Turnip Greens	29	588%
Parsley	11	554%
Broccoli	55	245%
Brussels Sprouts	56	243%

Basic Description

If you've read about vitamins A, B, C, D, and E, you might feel like we've missed a few vitamins as we jump over to vitamin K. But there are no vitamins F through J (at least not yet). Vitamin K is named after the German word for blood clotting (*koagulation*). In fact, this is probably the most common connection that people make with vitamin K—they associate this vitamin with the process of blood clotting. We'll explain more about this function of vitamin K in our "Role in Health Support" section below. However, it's important to know that vitamin K makes a variety of unique contributions to our health, and our knowledge about these contributions has been expanding in new and unexpected ways.

There are three basic types of vitamin K. Their common names are K1, K2, and K3.

The K1 form of vitamin K is found in plant foods, and 44 of our WHFoods are plant foods that serve as excellent, very good, or good sources of vitamin K! Many of our best sources of this vitamin are green vegetables (including 16 excellent sources); this makes good sense since K1 is required for green plants to conduct the process of photosynthesis. The K2 form of vitamin K is made from K1 and K3 by bacteria and other microorganisms. It can also be made in the human body through a conversion process involving K1 and K3.

In plant foods, you won't find much preformed K2, unless those plant foods have been fermented or otherwise transformed by bacteria or other microorganisms. Certain microorganisms can convert K1 into K2. A great example is *Bacillus natto*. This bacterium can convert K1 into K2 and it is often used in the production of fermented soy products. In fact, this practice is so common that you will sometimes find the word "natto" being used to refer to these foods. Fermented soyfoods on our WHFoods list—including tempeh and miso—can contain significant amounts of K2. (And as plant foods, they also naturally contain K1.) Most of our WHFoods animal foods also contain K2, although the amounts are relatively small and insufficient to qualify them as excellent, very good, or good sources of vitamin K.

A third type of vitamin, found preformed in food but in very small amounts, is menadione, or vitamin K3. We don't yet have good research on the health role of these small of K3 amounts in food.

Role in Health Support

Blood Clotting

As mentioned in the Description section, vitamin K is perhaps best known for its role in the blood clotting process. When people hear the term "blood clot," they might sometimes jump to the conclusion that a blood clot is bad. But there are many times when it is very important for our blood to clot. For example, blood clots are necessary to stop bleeding when our skin gets punctured.

Yet at the same time, people are correct when they say that blood clotting can cause problems. For example, if the inside of a blood vessel has become too narrow due to the buildup (over time) of plaque, this plaque can sometimes rupture and our body

may form a blood clot in order to seal off the ruptured plaque. However, this blood clot might also end up stopping the flow of blood through the blood vessel since the blood vessel had become overly narrowed from the buildup of plaque.

Regardless of the specific situation, vitamin K is necessary for blood clots to form. The clotting process is very complex, requiring at least 12 proteins to function before the clotting process can be completed. Four of these protein clotting factors require vitamin K for their activity.

Luckily, we rarely see vitamin K deficiency lead to impairment in the clotting process in adults. We see it in newborns because vitamin K does not efficiently cross the placenta to the fetus, and it can take several weeks for the fetus to build up dietary stores. We also occasionally see clotting problems related to vitamin K deficiency in persons with severe liver or gastrointestinal diseases. But vitamin K deficiency basically never causes insufficient clotting disorders in healthy adults.

In contrast to insufficient clotting in healthy adults, we do see vitamin K deficiency becoming involved in unwanted clotting. This process once again involves the activity of multiple vitamin K-dependent enzyme systems, most importantly a system called matrix Gla protein.

It is currently somewhat of an open question how important vitamin K is to the progression of clot formation and heart disease. Researchers have sometimes, but not consistently, been able to correlate low vitamin K intake with increased risk of heart disease.

One problem in interpreting this research, however, is separating out the effect of healthy foods from the nutrients they contain. Even casual readers of this site are probably aware that the same green leafy vegetables that are our richest sources of vitamin K1 are also among the best sources of many other heart-protecting nutrients. Included in this heart-protective list from green leafy vegetables would be the vitamins A (in the form of carotenoids), C, E and B6, the minerals potassium and magnesium, and dietary fiber.

Researchers have attempted to answer this question by giving vitamin K in pill form at amounts similar to those found in the diet. Over a three-year period, 500 mcg of vitamin K—about the amount found in one serving of mustard greens—was associated with slightly slower progression of hardening of the arteries of the heart.

Given the preliminary and somewhat contradictory nature of this research, we would characterize the association between diets high in vitamin K and protection against coronary artery disease to be plausible, but still unproven.

Bone Health

Vitamin K is a fascinating nutrient with respect to bone health, and unlike some of the open-ended questions related to clotting, knowledge about the role of vitamin K nourishment in bone support is fairly well-established. Individuals who are vitamin K deficient have repeatedly been shown to have a greater risk of fracture. In addition, for women who have passed through menopause and have started to experience unwanted bone loss, vitamin K has clearly been shown to help prevent future fractures.

Bone support involves different forms of vitamin K

Research has shown that our bone cells take up vitamin K in the form of K1 as well as K2, suggesting that these forms of the vitamin may play different roles in the health of our bone. In the case of K2, researchers have also become interested in two particular subtypes of K2 called MK-4 and MK-7, which appear to be uptaken by our bone cells in preference to other subtypes. In fact, research on bone health is partly responsible for getting researchers more and more interested in the whole issue of vitamin K2 subtypes. Vitamin K2 contains a chemical "tail" composed of repeating units called prenyl units. The most common forms of K2 contain either 4,5,7,8, or 9 prenyl units, and are therefore referred to as MK-4, MK-5, MK-7, MK-8, and MK-9. (The letter "M" in "MK" refers to "menaquinone"—the scientific name for the K2—and the "K" refers to the common name of vitamin K.) While human diets usually consist of about 10-25% K2, the proportion of these different K2 forms can vary widely. Fermented soy foods (mentioned earlier in this article as an important source of K2) tend to have greater amounts of MK-7. Cheese may have greater amounts of MK-8 and MK-9. However, in the average U.S. diet, MK-4 typically accounts for about one-third or more of all K2 due to its presence in eggs and meats.

How bone support works

The bone-related benefits of vitamin K appear to depend on at least two basic mechanisms. The first of these mechanisms involves a type of bone cell called osteoclasts. Osteoclasts are bone cells in charge of bone demineralization—they help take minerals out of the bone and make them available for other body functions. While the activity of these cells is important for proper health, we do not want too many osteoclasts (or too much activity by osteoclasts) since those imbalances would mean

too much demineralization of bone. Vitamin K helps our body keep this process in check. The MK-4 form of vitamin K2 (also called menatetrenone) is known to block formation of too many osteoclasts, and perhaps also to initiate their programmed cell death (a process called apoptosis).

A second mechanism involves the role of vitamin K in a process called carboxylation. (This process is the same one discussed earlier in relationship to the stickiness of clotting factors required for proper blood clotting.) For our bones to be optimally healthy, one of the proteins found in bone—a protein called osteocalcin—needs to be chemically altered through the process of carboxylation. (Osteocalcin is not just any typical bone protein. It is a protein especially linked to our bone mineral density (BMD), and for this reason, it often measured in our blood when doctors are seeking to determine the health of our bone.) When too few of the osteocalcin proteins in our bone are carboxylated, our bones have increased risk for fracture. This unwanted risk appears to be particularly important with respect to hip fracture. Scientists refer to this bone problem as a problem involving "undercarboxylated osteocalcin" and they have determined that vitamin K can greatly improve the situation. Since vitamin K is required for proper activity of the carboxylase enzyme that allows carboxylation of the osteocalcin proteins in our bone, vitamin K can help restore these bone proteins to their proper place in our bone structure and strengthen the composition of the bone. In clinical studies, both K1 and K2 forms of vitamin K appear to play a role in osteocalcin carboxylation. Some studies show the K2 form (and specifically MK-4) to be especially helpful in postmenopausal bone protection.

Whether provided by the diet in the form of K1 or K2, this vitamin is becoming more and more focal in research on bone protection. Low levels of vitamin K intake are emerging as dietary risk factors for osteoporosis. Researchers have shown that increasing dietary vitamin K intake by 100 mcg per day—roughly doubling the average American adult intake for a time period of one full year—can lead to a significant increase in bone density in post-menopausal women. Low levels of vitamin K have also been associated with increased risk of arthritis. Low activity of vitamin K-dependent proteins inside the joints has been suggested as a likely mechanism for this increased risk.

Other Potential Health Benefits

Not suprisingly based on its role in photosynthesis and movement of electrons to generate energy, vitamin K may function as an important antioxidant nutrient especially in certain chemical forms (called "reduced" forms). In older men, vitamin K has been shown to help improve insulin resistance. In preliminary lab and animal studies, vitamin K has been investigated as a critical nutrient for protecting cells that line blood vessels, including both veins and arteries.

Summary of Food Sources

Both plant and animal foods can provide us with significant amounts of vitamin K. Fresh green vegetables are our most steadfast source of K1. At WHFoods, 16 of our green vegetables rank as excellent sources for this vitamin. Many of our Herbs & Spices—including parsley, basil, cilantro, sage, oregano and black pepper—also provide excellent amounts of vitamin K.

One serving of any food noted above will provide you with at least 10% of your daily vitamin K needs. In the case of kale—our top source of vitamin K—a 1-cup serving will provide you with over 1,000 micrograms, which is approximately 10 times the recommended minimum daily amount! Since the National Academy of Sciences has chosen not to set a maximal recommended intake level (Tolerable Upper Limit, or UL) based on available research, you will not be exceeding a recommended maximum amount even with ten times the minimum requirement (or greater amounts).

Outside of the vegetable family, you will find kiwifruit, blueberries, prunes, and grapes amount the most vitamin K-rich fruit sources, and soybeans and miso as two good legume sources. As mentioned earlier, most of our featured animal foods—including pasture-raised eggs, pasture-raised chicken, grass-fed beef, grass-fed lamb, grass-fed cheese, and grass-fed cow's milk—contain measurable amounts of vitamin K, as do shrimp, sardines, tuna, and salmon.

As you can see, nearly half of our WHFoods (44/100) rank as good, very good, or excellent sources of vitamin K. Your meal combinations for achieving ample vitamin K here are extensive. Still, as a fallback source for vitamin K1, you would most likely want to turn to dark green leafy vegetables since they typically provide 500-1,000 micrograms per serving. For vitamin K2, you would mostly likely want to turn to fermented plant foods (like miso or tempeh) or animal foods. As mentioned earlier, fermented plant foods and animal foods feature different subtypes of vitamin K2. Remember, however, that researchers know of no hard and fast requirement for consuming any set amount of preformed K2 from your meal plan since the cells of your body are able to take K1 and convert it into K2. This provides you with a lot of flexibility in choosing among the 40+ WHFoods that are ranked sources of this vitamin.

Common name	Vitamin K1	Vitamin K2	Vitamin K3

Scientific name	phylloquinones	menaquinones	menadiones
Food sources	plant foods, especially dark green leafy vegetables	meats, eggs, dairy, fish, fermented plant foods, fermented animal foods	not known to be provided in substantial, naturally occurring amounts in food

Introduction to Nutrient Rating System Chart

In order to better help you identify foods that feature a high concentration of nutrients for the calories they contain, we created a Food Rating System. This system allows us to highlight the foods that are especially rich in particular nutrients. The following chart shows the World's Healthiest Foods that are either an excellent, very good, or good source of vitamin K. Next to each food name, you'll find the serving size we used to calculate the food's nutrient composition, the calories contained in the serving, the amount of vitamin K contained in one serving size of the food, the percent Daily Value (DV%) that this amount represents, the nutrient density that we calculated for this food and nutrient, and the rating we established in our rating system. For most of our nutrient ratings, we adopted the government standards for food labeling that are found in the U.S. Food and Drug Administration's "Reference Values for Nutrition Labeling." Read more background information and details of our rating system.

World's Healthiest Foods ranked as quality sources of vitamin K						
Food	**Serving Size**	**Cals**	**Amount (mcg)**	**DRI/DV (%)**	**Nutrient Density**	**World's Healthiest Foods Rating**
Kale	1 cup	36.4	1062.10	1180	583.6	excellent
Spinach	1 cup	41.4	888.48	987	429.2	excellent
Mustard Greens	1 cup	36.4	829.78	922	455.9	excellent
Collard Greens	1 cup	62.7	772.54	858	246.4	excellent
Beet Greens	1 cup	38.9	696.96	774	358.5	excellent
Swiss Chard	1 cup	35.0	572.77	636	327.3	excellent
Turnip Greens	1 cup	28.8	529.34	588	367.6	excellent
Parsley	0.50 cup	10.9	498.56	554	911.4	excellent
Broccoli	1 cup	54.6	220.12	245	80.6	excellent
Brussels Sprouts	1 cup	56.2	218.87	243	77.9	excellent
Romaine Lettuce	2 cups	16.0	96.35	107	120.6	excellent
Asparagus	1 cup	39.6	91.08	101	46.0	excellent
Basil	0.50 cup	4.9	87.94	98	360.4	excellent
Cabbage	1 cup	43.5	71.40	79	32.8	excellent
Bok Choy	1 cup	20.4	57.80	64	56.7	excellent
Celery	1 cup	16.2	29.59	33	36.6	excellent
Kiwifruit	1 2 inches	42.1	27.81	31	13.2	excellent
Leeks	1 cup	32.2	26.42	29	16.4	excellent
Cilantro	0.50 cup	1.8	24.80	28	269.6	excellent
Sage	2 tsp	4.4	24.00	27	108.8	excellent
Green Beans	1 cup	43.8	20.00	22	9.1	excellent
Cauliflower	1 cup	28.5	17.11	19	12.0	excellent
Cucumber	1 cup	15.6	17.06	19	21.9	excellent
Tomatoes	1 cup	32.4	14.22	16	8.8	excellent
Oregano	2 tsp	5.3	12.43	14	46.9	excellent
Black Pepper	2 tsp	14.6	9.49	11	13.0	excellent
Green Peas	1 cup	115.7	35.68	40	6.2	very good
Blueberries	1 cup	84.4	28.56	32	6.8	very good
Grapes	1 cup	104.2	22.05	25	4.2	very good
Carrots	1 cup	50.0	16.10	18	6.4	very good
Summer Squash	1 cup	36.0	6.30	7	3.5	very good
Cloves	2 tsp	11.5	5.96	7	10.4	very good
Chili Peppers	2 tsp	15.2	5.71	6	7.5	very good

Soybeans	1 cup	297.6	33.02	37	2.2	good
Avocado	1 cup	240.0	31.50	35	2.6	good
Raspberries	1 cup	64.0	9.59	11	3.0	good
Winter Squash	1 cup	75.8	9.02	10	2.4	good
Pear	1 medium	101.5	7.83	9	1.5	good
Cranberries	1 cup	46.0	5.10	6	2.2	good
Miso	1 TBS	34.2	5.04	6	2.9	good
Bell Peppers	1 cup	28.5	4.51	5	3.2	good
Plum	1 2-1/8 inches	30.4	4.22	5	2.8	good
Cantaloupe	1 cup	54.4	4.00	4	1.5	good
Eggplant	1 cup	34.6	2.87	3	1.7	good

World's Healthiest Foods Rating	Rule
excellent	DRI/DV>=75% OR Density>=7.6 AND DRI/DV>=10%
very good	DRI/DV>=50% OR Density>=3.4 AND DRI/DV>=5%
good	DRI/DV>=25% OR Density>=1.5 AND DRI/DV>=2.5%

Impact of Cooking, Storage and Processing

Vitamin K is a fairly stable nutrient to most types of processing. Levels go down only slightly with common cooking techniques and tend to stay stable with storage.

Vitamin K in oils, but probably not in vegetables, is reduced by exposure to light. This is one reason, but certainly not the only one, that we recommend storing oils in dark areas and in opaque, sealed containers.

The hydrogenation process that is used to stabilize and solidify liquid fats damages a significant amount of the vitamin K content. This is just one of many reasons why we believe that hydrogenated fats should be avoided.

Risk of Dietary Deficiency

Average intake of vitamin K for U.S. adults has been estimated at approximately 80-85 micrograms per day, or about 70-90% of recommended intake. At WHFoods, we adopted the DRI standard for women 19 years and older of 90 micrograms per day as the one we use in our Nutrient Rating Charts, and on average, U.S. adults fall below this amount. In terms of age groups, adolescents and young adults have more risk of dietary deficiency than older adults, and men have more risk of deficiency than women, perhaps in part because the DRI for men age 19 years and older is 120 micrograms, or one-third higher than the DRI for women.

In light of the many foods that are rich in vitamin K—especially green vegetables—these averages tell us that on average, we are consuming very few green vegetables. For example, a single one-cup serving or broccoli each day would more than double our average vitamin K intake.

As described above, it would not take many food changes to help us move from our average marginal intake of vitamin K to a more optimal level. Increasing our intake of the World's Healthiest Foods would be a great way to make this shift, especially if green vegetables were given center stage.

Other Circumstances that Might Contribute to Deficiency

Apart from low dietary intake, the most common reason to see symptoms of vitamin K deficiency at least related to blood clotting involves use of medications that deliberately block the ability of vitamin K to help make blood clotting proteins. For people using these medications, there are specific medical reasons for trying to reduce vitamin K's ability in this regard. Anyone taking anti-coagulant medications should talk to their doctor about dietary intake of vitamin K and how to coordinate it with their overall health goals.

There are a few disease states that can interfere with vitamin K nutrition or utilization. For instance, any digestive disease that impairs absorption of fat-soluble nutrients may impair vitamin K uptake from foods. End-stage liver disease can also lead to symptoms of vitamin K deficiency. However, these problems are once again medical in nature, rather than lifestyle oriented and widely encountered by the general public.

Relationship with Other Nutrients

Both vitamin A and vitamin E can compete for absorption with vitamin K. To our knowledge, however, this has only been reported with mega-dose supplementation, not with dietary intake. As such, you probably do not need to eat in a certain pattern to protect your vitamin K nutrition, and you can enjoy the delicious taste of foods that are rich in all of these important nutrients.

Vitamin K works with the other nutrients important to bone health—calcium, vitamin D, and magnesium—to ensure that your skeleton stays strong. A deficiency of any of these nutrients can lead to problems that cannot be fully undone by focusing on other nutrients in the list.

Risk of dietary Toxicity

To our knowledge, there has never been a report of a person consuming a toxic dose of vitamin K from food, unless that person was taking a prescription medication specifically designed to affect vitamin K activity. Given the strong track record of safety, the National Academy of Sciences has chosen not to establish a Tolerable Upper Intake Level (UL) for vitamin K. Further evidence for the safety of dietary vitamin K comes from research studies where doses of vitamin K at 500 times the Dietary Reference Intake (DRI) level did not lead to observable toxicity.

The absence of a recommended maximum intake level is good news for anyone who enjoys vegetable-rich meals and especially those meals containing or more of our 44 top-ranked vitamin K-containing vegetables. Two or three of these vegetables can easily provide 10 times the WHFoods recommended intake amount of 90 micrograms. However, just to reiterate a point we made earlier in this section: risk of excessive vitamin K intake still applies to individuals who are taking prescription medications designed to regulate the activity of vitamin K, and any individual in this category should discuss dietary vitamin K intake with their healthcare provider.

Disease Checklist

- Blood clotting disorders
- Osteoporosis
- Coronary artery disease
- Cancer
- Liver disease
- Celiac disease
- Crohn's disease
- Ulcerative colitis
- Cystic fibrosis

Public Health Recommendations

In 2001, the National Academy of Sciences released a set of Dietary Reference Intakes (DRI) for vitamin K. These included a set of age and gender specific Adequate Intake Levels (AI) that are summarized in the following chart:

- 0-6 months: 2 mcg
- 6-12 months: 2.5 mcg
- 1-3 years: 30 mcg
- 4-8 years: 55 mcg
- 9-13 years: 60 mcg
- 14-18 years: 75 mcg
- 19+ years, female: 90 mcg
- 19+ years, male: 120 mcg
- Pregnant or lactating women, 14-18 years: 75 mcg
- Pregnant or lactating women, 19+ years: 90 mcg

The 2001 vitamin K DRIs did not include any Tolerable Upper IntakeLevels (ULs). We are not aware of any other public health organization that has issued a maximum level for dietary intake of vitamin K.

The Daily Value (DV) for vitamin K is 80 micrograms. This is the value that you'll see on food and supplement labels.

At WHFoods, we selected the DRI of 90 micrograms for women ages 19 and above as our recommended daily intake level.

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The World's Healthiest Foods

World's Healthiest Foods rich in zinc		
Food	Cals	DRI/DV
Beef	175	37%
Lamb	310	35%
Sesame Seeds	206	25%
Pumpkin Seeds	180	23%
Lentils	230	23%
Garbanzo Beans	269	23%
Cashews	221	21%
Turkey	167	18%
Quinoa	222	18%
Shrimp	135	17%

Basic Description

From a food standpoint, zinc may be a less familiar dietary mineral than iron or calcium or sodium, but it is no less important to our metabolism or our health. Like magnesium, zinc is used as a cofactor by a number of critical enzymes. (This "cofactor" status of zinc means that zinc participates directly in the activity of the enzymes.) In fact, more than 300 zinc-dependent enzymes are currently known. Even a mild dietary deficiency of zinc can have far-reaching health implications. Immunity, reproduction, skin health, and vision are just some of the areas that can be affected.

The importance of this mineral to multiple body systems makes it even more important for us to get an adequate amount of zinc in our daily diet. This task can be a very challenging one. Although there is some amount of zinc in all WHFoods, no individual food ranks as an excellent source of this mineral. Only five foods rank as very good sources, and 24 foods rank as good sources of zinc. If you are seeking to increase your dietary intake of zinc, this limited number of ranked foods means that you cannot count on any particular food to obtain your 11 milligrams of daily zinc. (This is the amount that constitutes the DRI, or Dietary Reference Intake level for this mineral.) Instead, you'll need to depend on the many different WHFoods groups and diversity in your meal plan. Our Summary of Food Sources section will provide you with additional recommendations in this area.

Like sodium and potassium, or calcium and magnesium, zinc and copper have overlaps in transport and metabolism. For this reason, balancing dietary zinc and copper sources may help prevent deficiency or excess of either mineral.

Role in Health Support

Immune Function

Diets low in zinc can induce measureable reductions in the activity of the immune system. These reductions occur relatively quickly—in as few as four weeks after starting a low-zinc diet—and are reversible upon getting zinc back into the body.

This experimental low-zinc diet only contained 2-3.5 milligrams of zinc per day, or less than you would have in a single serving of our Mediterranean-Style Salad.

It appears that elderly individuals are especially prone to developing reduced immunity related to poor zinc nutrition. Even in this at-risk population, restoring zinc status appears to reverse the detrimental changes within weeks.

One research group has gone so far as to recommend using a Mediterranean-style diet—a diet very similar to the World's Healthiest Foods approach—to protect against zinc deficiency in elderly individuals. We couldn't agree more.

Skin Health

Researchers have been able to induce acne symptoms in young men by feeding them diets deficient in zinc. This effect occurs surprisingly quickly, with one research group demonstrating a significant change in skin health within 12 days of depleted zinc

foods. Other researchers have been able to demonstrate a number of other skin and related symptoms, including facial rash, foot fungus, and canker sores. Again, each of these changes was reversed when zinc was brought back into the diet. While we don't want to overgeneralize about the significance of this study—and are by no means saying that most acne is caused by zinc deficiency—it does suggest that too little zinc from a meal plan can be a factor in compromising skin health, and that it's worthwhile building your zinc intake up to recommended levels in order to support the health of your skin.

Sensory Organs

Acute depletion of zinc can causes loss of the sense of taste and appetite. The level of zinc deficiency necessary to cause these changes appears to be more severe than the immune system changes reported above, and is often related to another factor such as cancer treatment or anorexia. One research group recently estimated that about 15% of elderly people who lost their sense of taste did so due to zinc deficiency, and some others did so due to more serious conditions; so make sure to report this symptom to your doctor if you develop it.

Like the other symptoms related to zinc deficiency, this change in sense of taste appears to be reversible in the majority of people who get back to normal zinc status. Here are a couple of recipes—Braised Red Curry Lamb and Vegetables as well as Healthy Chef's Salad with Walnuts and French Dressing—that should help to combat zinc-related loss of sense of taste, both by acting as good sources of zinc, and by including a good zing of spices.

Zinc is also critical to vision. It works together with vitamin A to help sense light and to send nerve impulses to the brain. Although we don't currently know how much of age-related vision loss is due to zinc deficiency, researchers have shown that zinc levels in the retina (the part of the eye that sees light) decline in tandem with vision loss.

Male Reproductive Health

Advanced deficiency of zinc can impair motility and number of sperm. In one study, young male volunteers ate a diet with only 10% of the Daily Value requirement (15 milligrams) for a little over a month. Researchers measured sperm quality and quantity before and after the zinc-deficient diet.

This study demonstrated that even brief periods of severe zinc deficiency can lead to measureable changes in sperm composition and quantity. Studies correlating diseases known to impair zinc nutrition with reduced fertility seem to second this conclusion. Here's a recipe—our 7-Minute Sautéed Crimini Mushroom—rich in zinc and selenium, another nutrient necessary for proper sperm production.

Summary of Food Sources

The most well-known fact about zinc in foods is almost certainly that oysters are rich in zinc. A typical oyster weighing approximately one ounce will contain about 8-9 milligrams of zinc. So two oysters would put you over the WHFoods recommended daily amount of 11 milligrams. In addition to oysters, other shellfish tend to be rich in this mineral, as are many other animal foods. Shrimp, for example, rank as our 10th best WHFoods source of zinc. And our Oyster and Clam Chowder recipe contains more than 400% of the DRI for zinc.

Statistically, red meat and poultry make up the biggest contributions to zinc intake in the diets of Americans. However, this statistic is somewhat misleading, since the two animal meats are quite different in their concentration of zinc. Grass-fed beef ranks as our top WHFoods source of zinc with 1 milligram in every ounce. However, pasture-raised chicken only ranks as our 44th best source of zinc, with only one-quarter milligram per ounce. (The reason that poultry makes such a large zinc contribution in U.S. diets is due to the large volume of poultry that we eat.) The bottom line here: if you enjoy both beef and chicken in your meal plan but want to focus on your intake of zinc, beef is your better option. Fish—including scallops and shrimp—are both good sources of zinc. After beef, our best WHFoods land animal source of zinc is lamb.

It is also true that many nuts and seeds are rich in zinc. Sesame seeds and pumpkin seeds, for example, rank in our Top 10 WHFoods sources for this mineral! And cashews are not far behind at our 11th best source. These nuts and seeds also provide the largest amounts of zinc to our 7-Day Healthiest Way of Eating Plan. For people eating a largely plant-based diet, these sources will be necessary on a daily basis to ensure a consistent intake of zinc. Shiitake mushrooms, crimini mushrooms, spinach, and asparagus are examples of very good plant-food sources of zinc. Among our WHFoods whole grains, quinoa and oats are you best zinc sources.

For most nutrients, there are a few food sources that stand out as providing most of a day's supply. Other than oysters, this is not true for zinc. Because of this, you'll need to have multiple contributors most days to reach your recommended intake level.

With 38 of our World's Healthiest Foods containing at least 1 milligram of zinc, you'll have a wide variety of items to choose from to make sure you meet your goal.

Introduction to Nutrient Rating System Chart

In order to better help you identify foods that feature a high concentration of nutrients for the calories they contain, we created a Food Rating System. This system allows us to highlight the foods that are especially rich in particular nutrients. The following chart shows the World's Healthiest Foods that are either an excellent, very good, or good source of zinc. Next to each food name, you'll find the serving size we used to calculate the food's nutrient composition, the calories contained in the serving, the amount of zinc contained in one serving size of the food, the percent Daily Value (DV%) that this amount represents, the nutrient density that we calculated for this food and nutrient, and the rating we established in our rating system. For most of our nutrient ratings, we adopted the government standards for food labeling that are found in the U.S. Food and Drug Administration's "Reference Values for Nutrition Labeling." Read more background information and details of our rating system.

World's Healthiest Foods ranked as quality sources of zinc						
Food	**Serving Size**	**Cals**	**Amount (mg)**	**DRI/DV (%)**	**Nutrient Density**	**World's Healthiest Foods Rating**
Beef	4 oz	175.0	4.09	37	3.8	very good
Spinach	1 cup	41.4	1.37	12	5.4	very good
Asparagus	1 cup	39.6	1.08	10	4.5	very good
Mushrooms, Shiitake	0.50 cup	40.6	0.96	9	3.9	very good
Mushrooms, Crimini	1 cup	15.8	0.79	7	8.2	very good
Lamb	4 oz	310.4	3.87	35	2.0	good
Sesame Seeds	0.25 cup	206.3	2.79	25	2.2	good
Pumpkin Seeds	0.25 cup	180.3	2.52	23	2.3	good
Garbanzo Beans	1 cup	269.0	2.51	23	1.5	good
Lentils	1 cup	229.7	2.51	23	1.8	good
Cashews	0.25 cup	221.2	2.31	21	1.7	good
Quinoa	0.75 cup	222.0	2.02	18	1.5	good
Turkey	4 oz	166.7	1.95	18	1.9	good
Shrimp	4 oz	134.9	1.85	17	2.2	good
Tofu	4 oz	164.4	1.78	16	1.8	good
Scallops	4 oz	125.9	1.76	16	2.3	good
Green Peas	1 cup	115.7	1.64	15	2.3	good
Oats	0.25 cup	151.7	1.55	14	1.7	good
Yogurt	1 cup	149.4	1.45	13	1.6	good
Beet Greens	1 cup	38.9	0.72	7	3.0	good
Summer Squash	1 cup	36.0	0.70	6	3.2	good
Broccoli	1 cup	54.6	0.70	6	2.1	good
Swiss Chard	1 cup	35.0	0.58	5	2.7	good
Brussels Sprouts	1 cup	56.2	0.51	5	1.5	good
Miso	1 TBS	34.2	0.44	4	2.1	good
Parsley	0.50 cup	10.9	0.33	3	4.9	good
Sea Vegetables	1 TBS	10.8	0.33	3	5.0	good
Tomatoes	1 cup	32.4	0.31	3	1.6	good
Bok Choy	1 cup	20.4	0.29	3	2.3	good

World's Healthiest Foods Rating	Rule
excellent	DRI/DV>=75% OR Density>=7.6 AND DRI/DV>=10%
very good	DRI/DV>=50% OR Density>=3.4 AND DRI/DV>=5%

good	DRI/DV>=25% OR Density>=1.5 AND DRI/DV>=2.5%

Impact of Cooking, Storage and Processing

Like other minerals, zinc in foods is remarkably stable to shelf storage. In fact, your foods will go bad long before the zinc content changes in any relevant way. But because many of the zinc-rich foods (meats, shellfish, and seeds, for instance) have such a limited shelf life for other reasons (like risk of bacterial contamination), you'll want to be careful in the way you store them.

Cooking meat does not lead to dramatic loss of zinc. So unlike some other minerals—for example, potassium—you don't need to be concerned here about losing too much zinc if you enjoy cooked meats in your meal plan. (And by the way, we do not recommend consumption of raw meat due to contamination risk.)

In plant foods, you can expect some zinc loss in cooking liquids, but this loss tends to be less than that seen with most other minerals. For example, boiled lentils lose about 10-20% of their zinc content. While this loss is not exactly irrelevant, in a practical sense, this still leaves lentils as a good source of dietary zinc (and given that lentils generally are not eaten raw you can know that by preparing them you are still enjoying a zinc-rich food).

Soaking beans, seeds, and grains for several hours, then allowing sprouts to form, may significantly improve zinc bioavailability from these foods.

Risk of Dietary Deficiency

While the average U.S. diet provides adequate zinc for most men and women, symptomatic zinc deficiency does sometimes occur in the U.S. Unlike for many of the other minerals, however, the beef-rich diet of many Americans (averaging about 1 pound of beef per week) tends to provide zinc in good supply. Not only beef, but other animal meats, provide us with substantial amounts of zinc, including grass-fed lamb and pasture-raised turkey. Perhaps the biggest risk of zinc deficiency in a healthy adult would occur in a person who consumed few animal foods and whose diet was largely based on processed foods, with no routine intake of nuts, seeds, fresh vegetables, or whole grains.

On average, U.S. children have sufficient intake of zinc. By the DRI standard described below, less than 5% of children in any age group are currently eating zinc-deficient diets.

While the above statistic might sound like good news, it isn't because children appear to be depending more and more on fortified foods—foods with extra added zinc in processing—rather than meeting their zinc needs from whole, natural foods. For example, ready-to-eat processed cereals have become an important source of zinc in kids' diets. This trend has three unwanted results. First, it leaves kids lacking in nutrients that are naturally present alongside of zinc in whole foods. Second, it leaves kids with imbalanced intake of zinc in relationship to other nutrients (like copper). And third, it puts kids at risk of excess zinc intake due to overconsumption of fortified processed foods. According to present-day research, nearly 90% of children under age 1, and 50% of those aged 1-3 years, eat more than the age appropriate upper limit of zinc daily.

Vegetarian diets tend to be a bit lower in zinc than diets that contain meat. Still, this difference is not as great as you might predict from looking at the food source lists below. According to a 2013 review of previously published research, vegetarians on average eat just under 1 mg of zinc less than meat-eaters in their daily diets. If you eat a largely or fully vegetarian diet, including seeds on a daily basis might be a good step toward ensuring good zinc nutrition.

Other Circumstances that Might Contribute to Deficiency

In addition to poor dietary supply, increased need for zinc (beyond our typical everyday needs) can also contribute to a relative deficiency of this nutrient. Infections, trauma, stress, and steroid medications are just some of the examples of situations where body tissues take up extra zinc from the blood, creating a relative deficiency.

Serious gastrointestinal problems can impair the ability to absorb zinc from foods. For example, more than half of people with an inflammatory bowel disorder called Crohn's disease have evidence of zinc deficiency. If you have inflammatory bowel disease, you'll probably need some help from a doctor or nutritionist to ensure good vitamin and mineral intake.

Our bodies are able to somewhat compensate for a very low zinc intake by reducing the amount of the mineral lost in the urine and feces. People with kidney or bowel diseases may not be as equipped to respond to temporarily low-zinc diets as people

with normal organ function.

Relationship with Other Nutrients

Too much zinc in the diet or from dietary supplements can impair copper nutrition. This interaction can occur in two ways. First, copper and zinc may directly compete for absorption from our gastrointestinal tract. Second, diets high in zinc may lead to overproduction of a protein called metallothionein, a protein that binds both copper and zinc. This second type of interaction might turn out to be the most important type in this arena.

The takeaway message here is probably two-fold. First, focus on foods that are strong sources of both copper and zinc. Sesame seeds and pumpkin seeds would be good examples of these. Secondarily, using high doses of zinc supplements to circumvent the difficulty in finding good food sources may do as much or more harm as good.

Phytate—a phosphorus-rich molecule that may provide us with health benefits well beyond its phosphorus content—is also a molecule that can inhibit absorption of dietary zinc. (Phytate can inhibit the absorption of other minerals as well, including iron.) While phytate can be broken down in our large intestine by naturally occurring bacteria, it may not be a good thing to have too much zinc bound together with phytate, since zinc is typically absorbed from our digestive tract much earlier during the process of digestion. If too much zinc remains bound to phytate before the two can be separate, we may not be able to absorb as much zinc as would otherwise be desirable. As discussed earlier in this profile, sprouting grains and legumes may help reduce phytate levels to a significant degree. We would like to point out, however, that there is no research to suggest that consumption of non-sprouted whole grains and legumes in a balanced diet increases a person's risk of zinc deficiency.

Risk of dietary Toxicity

The major risk associated with excessive zinc intake is that you will crowd out the ability to absorb other important minerals. In particular, high zinc intakes impair absorption of copper, a nutrient we already struggle to obtain from our diets. Reduced copper absorption, in turn, can lead to anemia and a resulting fatigue.

Fortunately, it appears that all the published cases of excessive zinc intake involve either a nutritional supplement or a related non-dietary exposure (denture creams, for instance, can contain excessive amounts of zinc). It would be theoretically possible to obtain too much dietary zinc by eating several oysters every day, but this has never been reported to be a problem in published research studies, perhaps because oysters are also rich in the other minerals that compete with zinc for absorption.

There is a Tolerable Upper Intake Level (UL) set for zinc by the Institute of Medicine at the National Academy of Sciences of 40 milligrams per day. The basis for this recommended limit involved research on enzyme activity in red blood cells. (The enzymes required a special balance between copper and zinc to function properly, and too much zinc upset this balance.) As described earlier, a good balance of zinc and copper in food might be able to help offset possible problems even if zinc intake regularly exceeded the UL. It is always worth remembering that ULs set by the National Academy of Sciences refer to regular intake of nutrients on a routine basis, not occasional intake every once in a while.

Disease Checklist

- Common cold
- Acne vulgaris
- Down syndrome
- Canker sores
- Liver disease
- Ulcer
- Diabetes
- Depression
- Macular degeneration
- Infertility (male)

Public Health Recommendations

The 1999 Dietary Reference Intake (DRI) levels for zinc as established by the National Academy of Sciences are as follows:

- 0-6 months: 2 mg

- 7-12 months: 3 mg
- 1-3 years: 3 mg
- 4-8 years: 5 mg
- 9-13 years: 8 mg
- 14-18 years, female: 8 mg
- 14-18 years, male: 11 mg
- 19+ years, female: 8 mg
- 19+ years, male: 11 mg
- Pregnant women, 14-18 years: 12 mg
- Pregnant women, 19+ years: 11 mg
- Lactating women, 14-18 years: 13 mg
- Lactating women, 19+ years: 12 mg

All of the DRI recommendations above are Recommended Dietary Allowances (RDAs), except the recommendation for 0-6 month old infants, which is an AI (Adequate Intake) recommendation. (AI intake recommendations are somewhat less precise than RDA recommendations.)

The Daily Value (DV) for zinc is 15 mg per day for adults and children older than 4 years. DVs are the standards used on food packaging labels.

The National Academy of Sciences has set a Tolerable Upper Intake Level (UL) for zinc intake at 40 mg per day for adults. As noted in the toxicity section above, it would be very unusual to consistently be above this threshold by dietary intake alone.

As our WHFoods recommendation level for zinc, we chose the DRI standard for males 14 years and older of 11 milligrams. With the exception of pregnancy and lactation, this level covers the needs of females 14 years and older as well.

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